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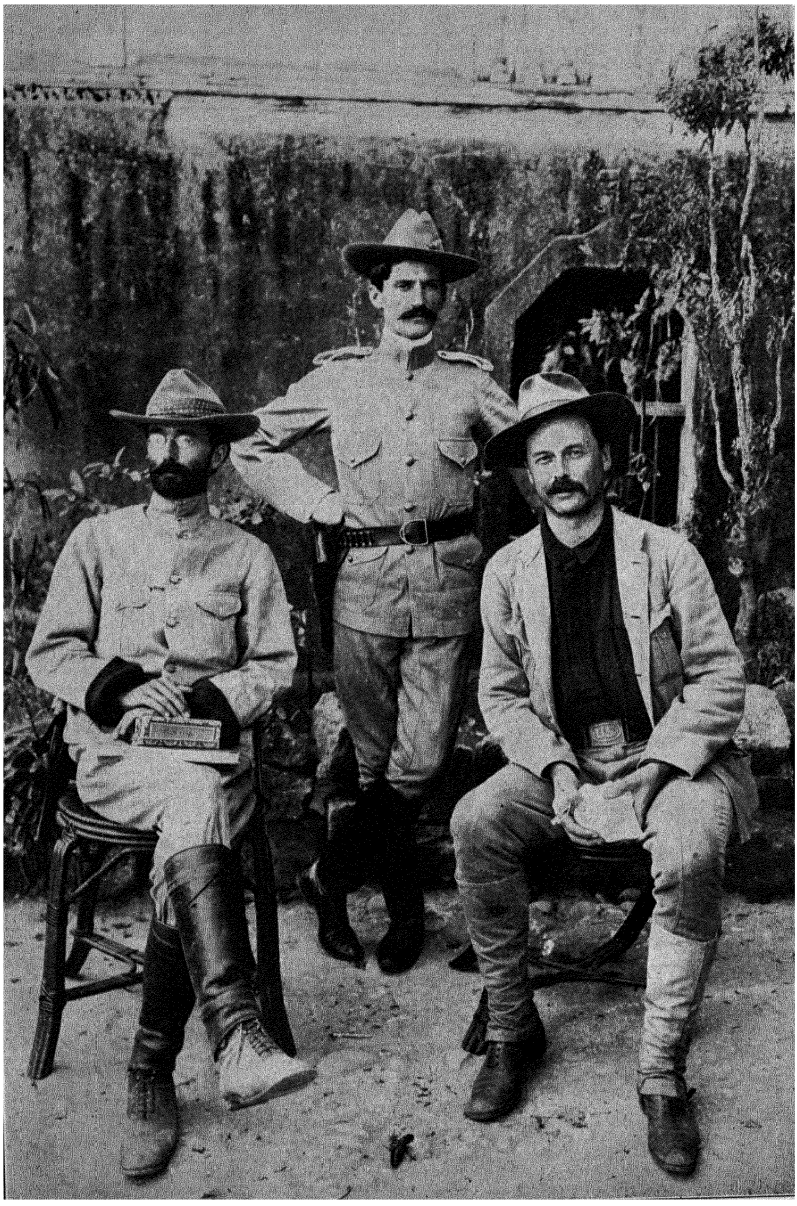
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THE FIRST AND SECOND CHIEFS OF THE PHILIPPINE MINING BUREAU: MR. H. D. McCASKEY SEATED ON THE LEFT; LIEUT. CHARLES H. BURRITT SEATED ON THE RIGHT.

GEOLOGY AND MINERAL RESOURCES OF THE PHILIPPINE ISLANDS

BY

WARREN D. SMITH



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TO THE MEMORY OF
HARRY M. ICKIS

Mining Engineer in the Division of Mines of the Bureau of Science, killed in the performance of duty on the Island of Mindanao about April 1, 1908, this volume is dedicated by one who shared in his last expedition.

FOREWORD

In continuation of the general policy of the Philippine Bureau of Science of making available to as large a public as possible our compiled data of economic and semi-economic importance, the present volume on the geology and mineral resources of the Philippines, prepared by Dr. Warren D. Smith, is presented. From an economic standpoint geologic data are of great value, not alone to those who are interested in the development of our mineral resources, but also to planters, engineers, and the general public. Available data on Philippine geology are widely scattered in technical literature, and it is impossible for anyone interested in the various phases of the science to secure in any single publication the local information that he requires. The present work, which it is hoped will meet the urgent needs of those vitally interested, summarizes our present knowledge of Philippine geology and mining and makes available the most essential data on the general geology of the Archipelago, specialized regional geology, seismology, volcanology, paleontology, and mineralogy. The economic geology of the Archipelago has been given special attention. Essential data in reference to the local governmental procedure, mining laws, land laws, forest regulations, corporation laws, etc., have been included in an appendix, in order to make the work more generally useful to those who may have occasion to consult it.

ELMER D. MERRILL,
Director, Bureau of Science.

MANILA, P. I., *October 30, 1923.*

CONTENTS

	Page.
ILLUSTRATIONS	9
INTRODUCTION	15
Past work	15
Scope of the present work	17
General features of Philippine geology	18
GEOGRAPHY	26
Position of the Philippines relative to other countries	26
History of Philippine exploration and cartography	27
Climate, population, flora, and fauna	34
PHYSIOGRAPHY	45
Discussion of Philippine physiography	45
Human response to physiographic conditions	61
Effects of modern improvements	66
STRATIGRAPHY AND CORRELATION	67
Correlation	67
Stratigraphy	71
PETROGRAPHY	93
The igneous rocks	93
The clastic rocks	102
The metamorphic rocks	105
GEOLOGIC HISTORY	111
REGIONAL GEOLOGY	115
Luzon	115
Marinduque	148
The Visayan Islands	152
Samar	153
Negros	154
Panay	177
Leyte	185
Biliran	189
Cebu	189
Bohol	195
Masbate	195
Romblon, Tablas, and Sibuyan	200
Mindanao	200
Basilan	244
Cagayan Sulu	244
Sulu Archipelago	245
Palawan-Cuyo-Mindoro group	248
Balabac	249
Palawan	250
Cuyo Islands	253
Calamian Islands	253
Apo Island	255
Semirara	256

REGIONAL GEOLOGY—Continued. Page.
Mindoro ... 256
Lubang Islands ... 258
Batanes and Babuyanes ... 261
SEISMOLOGY ... 270
VOLCANOLOGY ... 291
PALEONTOLOGY ... 309
MINERALOGY ... 333
ECONOMIC GEOLOGY ... 351
Nonmetallic minerals ... 358
Abrasives ... 358
Alum ... 358
Asbestos ... 358
Bituminous rock ... 361
Cement ... 361
Clay and clay products ... 362
Coal ... 363
Corundum ... 384
Gems and precious stones ... 384
Guano and phosphates ... 384
Gypsum ... 384
Lime ... 385
Mica and talc ... 385
Ocher ... 385
Petroleum and residual bitumens ... 385
Rock, sand, and gravel ... 394
Salt ... 394
Stone ... 395
Sulphur ... 395
Mineral waters ... 399
Metallic minerals ... 404
Chromite ... 404
Copper ... 404
Gold ... 409
Iron ... 446
Manganese ... 464
Lead and zinc ... 464
Molybdenite ... 465
Platinum ... 466
Silver ... 466
Wolframite ... 466
HISTORY OF MINING IN THE PHILIPPINE ISLANDS ... 467
BIBLIOGRAPHY ... 478
INDEX ... 521
APPENDIX ... 537
Outline of Philippine Government ... 537
Abstract of Philippine Mining Laws and Regulations ... 539
Philippine Forests and Timbers ... 543
Mineral Lands and Mine Operators ... 550
Glossary of Philippine Mining Terms ... 559

ILLUSTRATIONS

FRONTISPIECE

The first and second chiefs of the Philippine Mining Bureau: Mr. H. D. McCaskey seated on the left; Lieut. Charles H. Burritt seated on the right.

PLATE 1

Shales and agglomerate in Suqui Creek, Cebu.

PLATE 2

Rubble Pliocene (?) limestone exposed in a gorge of Danao River, Cebu.

PLATE 3

FIG. 1. Malumbang limestone cliffs at Sagada, Mountain Province.
2. Limestone needles at Sagada, Mountain Province.

PLATE 4. THIN SECTIONS OF ROCKS FROM BAGUIO

FIG. 1. Hypersthene-augite andesite from Baguio, No. 106; × 9, ordinary light.
2. Quartz diorite, Baguio, No. 12; × 15, polarized light.

PLATE 5. JURASSIC (?) RADIOLARIA

FIG. 1. Thin section of old "slate" of probable Jurassic age, containing Radiolaria; × 100.
2. A portion of the section shown in fig. 1; × 200.

PLATE 6

FIG. 1. Orbitoidal limestone from Cebu, showing *Lepidocyclina*.
2. Serpentine from Batan Island.

PLATE 7

FIG. 1. Foraminiferal limestone from locality F878, north of Catbalogan, Samar.
2. Coarse-grained limestone conglomerate from locality F869, southeast of Catbalogan, Samar, near rock quarry, showing association of *Lepidocyclina* with igneous pebbles.

PLATE 8

Lithothamnium ramosissimum Reuss.

PLATE 9. VIGO GROUP, MIOCENE FOSSILS

FIG. 1a. *Vicarya callosa* Jenkins; × ¾. Bureau of Science locality F17. Tunnel 14, Sibuguey Peninsula, Mindanao; collector, F. A. Dalburg. This "finger post" of the Malaysian Miocene is found at numerous localities in the Philippines, and as a rule the strata containing specimens are associated with the coal seams, or lignitic strata.

FIG. 1b. *Vicarya callosa* Jenkins; × ⅘. Bureau of Science locality 7. Gray shale overlying the East Batan coal seam in the Perseverancia claim, Batan Island; collector, F. A. Dalburg. This picture illustrates the size and peculiar character of the callosity as developed upon a mature specimen.

1c. *Vicarya callosa* Jenkins; × ⅘. Bureau of Science locality 7. Showing spire whorls of a mature specimen.

2. *Voluta innexa* Reeve; × ¾. Bureau of Science locality 272, Cebu.

3. *Arca ferruginea* Reeve; × ⅞. Locality 4x.

4. *Arca granosa* Linnæus; × ⅞. Locality 3x.

5. *Arca tenebrica* Reeve; × 2. Locality 5x.

6. *Arca* sp.; × 2. Locality 2x.

7. *Cardium elongatum* Bruguiere; × ⅞. Locality 11x.

8a. *Cardium unicolor* Sowerby; × ⅞. Locality 11x.

8b. *Cardium unicolor* Sowerby; × ⅞. Locality 11x.

9a. *Cardium donaciformis* Cuming; × ⅘. Locality 2x.

9b. *Cardium donaciformis* Cuming; × ⅘. Locality 2x.

10. *Cardita antiquata* Linnæus; × ⅞. Locality 11x.

11. *Corbula socialis* K. Martin; × ⅚. Locality 3x.

12a. *Corbula* sp.; ×⅘. Locality 3x.

12b. *Corbula* sp.; × ⅘. Locality 3x.

13a. *Corbula scaphoides* Hinds; × ⅚. Locality 3x. View of right valve of small specimen.

13b. *Corbula scaphoides* Hinds; × ⅘. Locality 3x. View of left valve, which is much smaller than right.

14. *Dosinia cretacea* Philippi; × ⅘. Locality 9x. Dumalog Creek, Bondoc Peninsula, Tayabas Province, Luzon.

15a. *Glycimeris viteus* (Lamarck); × ⅞. Locality 11x. View showing hinge.

15b. *Glycimeris viteus* (Lamarck); × ⅞. Locality 11x.

16a. *Lucina* cf. *argentia* Reeve; × 2. Locality 11x. This form is semitransparent and the ribbing corresponds to Reeve's species, but the shape is somewhat different.

16b. *Lucina* cf. *argentia* Reeve; × 2. Locality 11x.

17. *Ostrea* sp.; × ⅞. Locality 5x.

PLATE 10. MALUMBANG FORMATION, PLIOCENE FOSSILS

FIG. 1a. *Pecten naganumana* Yokoyama; × ⅔. This species was described by Dr. Yokoyama, of the Imperial University of Tokyo, from the Lower Musashino formation of probable upper Pliocene age.

1b. *Pecten naganumana* Yokoyama; × ⅔. Convex right valve.

2. *Spondylus* sp.

3. *Spondylus imperialis* Chemnitz; × ⅚.

4. *Venus squamosa* Lamarck; × ⅚. Bureau of Science locality 1054.

5. *Fungia* sp.; × ⅘. Bureau of Science locality.

6a. *Flabellum* cf. *australe* Moseley; × 9/11.

6b. *Flabellum* cf. *australe* Moseley; × 9/11.

7. *Leptoria* sp.; × ¾. Locality 6x.

PLATE 11. PLEISTOCENE FOSSILS

Fossils from raised coral reefs near San Andres, Bondoc Peninsula, Tayabas Province. About one-half natural size. (After Pratt and Smith.)

FIG. 1. *Conus flavidus* Lamarck.
2. *Strombus* sp.
3. *Strombus* sp.
4. *Potamides* sp.
5. *Spondylus* sp.
6. *Telescopium telescopium* Linnæus.
8. *Trochus fenestratus* Gmelin.
9. *Crista pectinata* Linnæus.
10. *Cerithium nodulosum* Bruguiere.
11. *Circe pectinata* Linnæus.
12. *Potamides* sp. Youthful individual of the form shown in fig. 4.
13. *Arca cornea* Reeve.
14. *Strombus canarium* Linnæus.

PLATE 12. MALUMBANG FORMATION, PLIOCENE FOSSILS

Fossil plants from Sagada, Mountain Province, Luzon. The figured specimens were identified by Mr. Elmer D. Merrill, of the Bureau of Science.

FIG. 1. *Beilschmiedia cairocan* Vidal. An endemic species of the Lauraceæ.
2. *Phoebe sterculioides* Merrill. An endemic species of the Lauraceæ.
3. *Anamirta cocculus* Wight and Arnott. An Indo-Malaysian species of the Menispermaceæ.
4. *Shorea polysperma* Merrill. An endemic species of the Dipterocarpaceæ.

PLATE 13

Map of a portion of the central plain of Luzon.

PLATE 14

Map of the eastern portion of Laguna de Bay and the adjacent topography.

PLATE 15

Topographic map of the Benguet mineral region.

PLATE 16

Eruption cloud above Taal Volcano as it appeared from Banadero, January 30, 1911. (Photograph by Charles Martin.)

PLATE 17

FIG. 1. Topography in the vicinity of Pidatan oil seep, Mindanao.
2. Mount Kitubud (Pliocene limestone) and valley of the Malitabug.

PLATE 18

FIG. 1. Andesitic agglomerate in Tumaga River, Zamboanga Peninsula.
2. Section of volcanic tuff, showing concretionary structure from near the base of Mount Maquiling, at an altitude of about 80 meters.

PLATE 19

FIG. 1. Abra Water Gap, east of Vigan, Ilocos Sur, Luzon. (Photograph by H. G. Schenck.)
2. Mount Data Plateau. (Photograph by W. D. Smith.)

PLATE 20

FIG. 1. Conglomerate beds at Klondyke's, Bued River, Luzon.
2. Terraces at Salinas salt spring, Nueva Vizcaya, Luzon.

PLATE 21

FIG. 1. Palidan slide, Suyoc, Mountain Province, Luzon.
2. Igorots stoping in Palidan slide, Suyoc.

PLATE 22

Relief map of the Aroroy district, Masbate.

PLATE 23

Interior of a typical dipterocarp forest on the lower slopes of Mount Silay, Negros. The trees are red lauan and almon, species of *Shorea*.

PLATE 24

Model of a Filipino dredge in use in Camarines Norte, Luzon, in 1908.

PLATE 25

A view in Cebu, showing alluvial clay flood plain of Pandan River in the foreground; Pliocene limestone beds dipping toward the sea in the distance.

PLATE 26

Malumbang (Pliocene) limestone monadnock, site of the Batwaan caves, Masbate.

PLATE 27

Underground river in St. Paul's Bay, Palawan. Photograph taken within the cavern and looking toward the exit.

PLATE 28

Angat River at Paila, Bulacan Province, Luzon, showing proposed dam site of water-supply project of the Metropolitan Water District.

PLATE 29

Mayon Volcano, Albay Province, Luzon; Legaspi in the foreground. Photograph taken at 15 kilometers from the summit.

PLATE 30

Montalban Gorge, Rizal Province, Luzon, in Miocene limestone cliffs.

PLATE 31

Mount Apo, as seen from Digos on Davao Gulf, Mindanao.

PLATE 32

Canlaon Volcano, Negros; interior of the crater.

PLATE 33

Benguet Consolidated mill, Antamok, Mountain Province, Luzon.

PLATE 34

Topographic map of Mount Banahao, Laguna Province, Luzon.

PLATE 35

Plan and elevation of the vein system on the Syndicate property, Aroroy, Masbate.

PLATE 36

Map of the Sibuguey coal field, Mindanao.

PLATE 37

Relief map of the Philippine Islands.

PLATE 38

Mineral map of the Philippine Islands.

PLATE 39

Geologic map of the Philippine Islands.

TEXT FIGURES

Page.

FIG. 1. Map of the world, showing the central position of Manila in the Far East 26
2. Geologic sketch map, showing the geology along Trinidad River in the vicinity of Baguio, Mountain Province, Luzon. (After Dickerson.) 53
3. Geologic section near San Fernando, La Union Province, Luzon. (After Eddingfield.) 126
4. Plan and section of the hospital-hill landslide near Baguio, Mountain Province, Luzon. (After Lednicky.) 128
5. Generalized geologic section across northern Luzon, from Tagudin to the east coast 134
6. General geologic section across Luzon, from Infanta to Tanay. (After Ickis.) 141
7. Geologic sections through the iron-ore region of Bulacan, Luzon, diagrammatic in part; *a*, post-Miocene sediments; *b*, Miocene sediments; *c*, granite; *d*, effusives with intrusives; *e*, intrusives with effusives. (After Dalburg and Pratt.) 142
8. Generalized geologic section across Negros 157
9. Geologic section along Tigum River, across Iloilo Province, Panay 182
10. Geologic section across a part of Cebu. (After Abella.) 193
11. Geologic section across strike of beds at Toledo, Cebu; partly diagrammatic; *a*, coralline limestone; *b*, tuff and agglomerate; *c*, Miocene shales, sandstones, conglomerates, and limestone; *d*, basal igneous complex. (After Pratt.) 194
12. Geologic section across strike of beds along Malbog Creek, Alegria, Cebu; *a*, coralline limestone; *b*, volcanic tuff; *c*, Miocene shales and sandstones over limestone. (After Pratt.) 194

Page.

FIG. 13. Map of the drainage system of Cagayan de Misamis River, Mindanao. Topography along Tagoloan River, by H. M. Ickis 209
14. Profile from Camp Overton to Malabang, Mindanao 211
15. Generalized geologic section east and west through Pidatan oil seep, Cotabato, Mindanao 231
16. Earthquake map of the Philippine Islands. Figures indicate seismic regions; stars, approximate epicenters; straight lines, main structural lines of the Archipelago 280
17. Map of the crater of Taal Volcano prior to January 1, 1911; from a topographic map by S. B. Coleman. Scale about 1:25,000 296
18. Sketch map of the crater of Taal Volcano made February 17, 1911; the great eruption occurred on January 30, 1911. Dotted line shows contour of crater lake on April 9, 1911, as observed by W. D. Smith. Scale about 1:25,000 296
19. Idealized geologic section from Pasuquin, Ilocos Norte Province, Luzon, northeast to cordillera 360
20. Plan of the underground workings of the Santa Barbara copper mine, in Mankayan, Lepanto Subprovince, Luzon. Survey by Goodman and Ickis 408
21. Mill flow sheet of the Benguet Consolidated Mining Co.; crushing plant 431
22. Mill flow sheet of the Benguet Consolidated Mining Co.; treatment plant 432
23. Gold veins on the Kelly property, near Baguio, Mountain Province, Luzon. (After Eddingfield.) 434

GEOLOGY AND MINERAL RESOURCES OF THE PHILIPPINE ISLANDS

By WARREN D. SMITH

INTRODUCTION

PAST WORK

It is now twenty years since Becker's admirable summary of Philippine geology was issued. Since that time, our geologic knowledge of the Archipelago has been greatly increased, not so much along general lines as in detail. The broader features were brought out principally by the foremost Spanish geologist, Abella y Casariego, as well as by Becker, whose chief contribution was a correlation and summary of previous work.*

Of the workers who antedated the coming of the Americans to this land, many were merely passing travelers, and these contributed only fragmentary and cursory notes, but the following must be particularly mentioned:

Richard von Drasche, a German geologist, who traveled extensively in Luzon in the decade 1870 to 1880.

Karl Oebbeke, a German petrographer, who was never in the Archipelago, but who worked on von Drasche's collections.

Karl Martin, a Dutch paleontologist of note and the authority on the paleontology of Java, who has studied collections of Philippine fossils, but has never visited the Islands.

B. Koto, dean of Japanese geologists, who has never been here, but whose discussion of Malaysian tectonics is suggestive and helpful.

José Centeno, chief of the Spanish mining bureau from 1876 to 1886, who contributed much to the geologic literature of the Islands; his chief work was on Taal Volcano.

Enrique Abella y Casariego, the last chief † of the Spanish mining bureau, 1889 to 1897, was by far the ablest of the earlier investigators. It is a great pleasure to pay this tribute to our late colleague of another nationality. I have only words

* See Bibliography, page 482.

† Luis Espina y Capo was acting chief just prior to the American occupation.

of commendation for his untiring efforts in the solution of the geologic and mining problems of the Philippines.

When, in 1901, the United States Government established the Mining Bureau under Lieut. Charles S. Burritt, the first definite step was taken to procure up-to-date, detailed information about the mineral resources of the country. To this man is due the credit for the early organization of the work and for much painstaking labor on the Spanish records and literature. He was succeeded by H. D. McCaskey, a mining engineer, whom he had chosen especially to investigate the metallic resources. Mr. McCaskey's six years of service saw the work greatly increased in scope, and his labors, while not so noticeable in the literature, were great and constructive. Mr. McCaskey soon augmented his staff to four technical men, and carried the work through the second period to the union of the Mining Bureau with the Bureau of Government Laboratories under the new name, Bureau of Science. This was in 1906. The staff of the old Mining Bureau at that time consisted of the following:

Hiram Dryer McCaskey, chief.
Arthur J. Eveland, mining engineer, metals.
Warren Du Pré Smith, geologist, nonmetals, and paleontology.
Maurice Goodman, mining engineer and field assistant.
Harry M. Ickis, mining engineer and field assistant.
Hugo Navarro, draftsman.
Gabriel M. de Ubago, property and record clerk.
R. C. Redmayne, chief clerk.

When the consolidation took place, Mr. McCaskey resigned and took a position on the United States Geological Survey. W. D. Smith became acting chief of the division of mines in the Bureau of Science in 1907, and chief in 1908, which post he held until his resignation in 1914. He was succeeded by Wallace E. Pratt. At the close of 1913, the staff consisted of the following:

Warren Du Pré Smith, chief.
Frank T. Eddingfield, mining engineer, metals.
Wallace E. Pratt, geologist, nonmetals.
Frank A. Dalburg, coal engineer.
Paul R. Fanning, metallurgist.
Randall A. Rowley, petrographer, special assistant from the University of the Philippines.
Feliciano Nable, field assistant.
Pio Moskaira, chief draftsman.

The following factors combined to make the next period, from 1907, the most productive: The restoration of stable and safe conditions throughout the Archipelago; the connection with the

Bureau of Science, where there were far better facilities; the organization that had been effected; and the opening of various mining districts, which furnished data not previously available.

In 1920 I returned to the Philippines and again became chief of the division of mines, for two years.

SCOPE OF THE PRESENT WORK

It is felt that the time is ripe to collect into one volume a summary of all information of interest to geologists, mining engineers, students, and mining investors.

Special acknowledgment is due to Dean C. Worcester, ex-Secretary of the Interior, who in the early years did much to foster scientific work in the Philippines; to the work of the late Paul C. Freer, the able and kindly first director of the Bureau of Science; to H. D. McCaskey, second chief of the Philippine Mining Bureau, afterward on the staff of the United States Geological Survey, and now retired; and to Elmer D. Merrill, the present director of the Bureau of Science, who has assisted in many ways in the preparation of this book, in securing funds for travel, in contributing important data, and in securing funds for its publication.

I have drawn freely upon the published writings of my colleagues of later years, and the present work would not be possible without their contributions. I alone am responsible for the interpretation of their data. The men whom I desire especially to credit are, in order of their connection with the division of mines:

H. D. McCaskey.
Maurice Goodman.
Harry M. Ickis.
Arthur J. Eveland.
Henry G. Ferguson.
Wallace E. Pratt.
George I. Adams.
Frank T. Eddingfield.
Paul R. Fanning.
Frank A. Dalburg.
Feliciano Nable.
Victor E. Lednicky.
J. P. Goldsberry.
Victoriano Elicaño.
Leopoldo Faustino.

Two investigators outside the Bureau of Science also deserve special acknowledgment. Father Miguel Saderra Masó, S. J., of the Philippine Weather Bureau, has collaborated with me in the chapters on Seismology and Volcanology, and association with him has been inspiring. Dr. Roy E. Dickerson, honorary curator of the department of paleontology, California Academy of Sciences, who has been making special investigations in the Philippines, has assisted me by a critical reading of the manuscript and in many other ways to an extent greater than I can

adequately acknowledge. The friendly and helpful criticism of these two men has been a most pleasant experience.

Mr. Richard C. McGregor and Mrs. Anna B. Banyea, of the Philippine Journal of Science, have edited the manuscript, and I here record my appreciation of their labors.

It is hoped that those who peruse these pages will not forget that the data compiled here were obtained under conditions such as do not exist in the United States, that much of the information of necessity cannot be final or accurate, and that we have been able merely to blaze a slightly wider trail than existed before. This book is published as an aid to future workers who will be in a position to do more careful and more detailed work than was possible for us.

GENERAL FEATURES OF PHILIPPINE GEOLOGY

Structurally, the Philippine Archipelago may be considered as the crumpled edge of the Asiatic continental platform. A study of the hydrographic charts (Plate 37) of this region reveal many interesting features; but the most important, perhaps, is the great foredeep close to the eastern margin of the group, in which the deepest known part of the Pacific is located, 85 kilometers northeast of Mindanao. This foredeep is undoubtedly related to the similar deeps off the east coasts of Formosa and Japan, and from this it would seem that these three island groups ought to bear about the same relationship to the mainland. However, it seems that between the Philippines and Formosa there is lack of connection marked by the deep Bashi Channel. None of the Paleozoic rocks reported from Formosa has been discovered in the Philippines. The supposition that there is perhaps a difference in geologic history in these groups is confirmed by testimony from botanists, who say that the affinities in Formosa are all with Asia, while in the Philippines they are largely with Celebes, New Guinea, and Borneo. Similar relationships hold in the matter of faunas.*

West of the Archipelago is the much lesser deep of the China Sea, presumably a sunken area, or Graben. This China Sea Graben is undoubtedly analogous to the submerged area between New Zealand and Australia, and the Asiatic mainland may bear the same relation to the Philippines that Australia does to New Zealand.

* The large and important subject of the paleogeography of this region and the bearing it has upon the distribution of plants and animals will only be hinted at here.

The two long and comparatively narrow interrupted land bridges between Borneo and the Philippines by way of Palawan and the Sulu Archipelago, respectively, are significant features in the present framework of the Archipelago. These and many other important points may be readily seen on studying the composite hydrographic relief map (Plate 37).

The land areas of the Philippines are merely the higher portions of a partly submerged mountain mass, in part the crests of anticlinoria, in part the upthrust blocks or horsts caused by faulting, in part the summits of volcanoes. Some of the straits, consequently, are the downfolded areas or synclines, while others are Graben. The structure of the Archipelago is by no means as simple as was at first thought. Besides the folding and faulting mentioned, there are volcanic intrusives and volcanic extrusives of different periods, which further complicate matters.

As to the geologic time of the major deformations it can be stated with a fair degree of certainty that there was a period of intense deformation prior to the Tertiary when some of the schists were formed, although some schists appear very clearly to be the result of strong movements in Tertiary times. Toward the end of the Miocene, the widespread "Miocene Revolution," the Vigo and Batan formations were generally folded, in some places intensely crumpled and faulted. Again, late in the Pliocene, or early in the Pleistocene, as shown by the Malumbang, there was another period of folding, though not so pronounced.

Finally, beginning with the Pliocene and continuing through the Pleistocene and Recent, much of the Archipelago has been subjected to a great uplift, amounting to some 1,800 meters in Luzon. Evidence of this is found in the fact that fossil plants, very closely related to species living in the lowlands near Manila, have been discovered in the extreme highlands of Luzon. It appears to me that the latest elevation has been not uniform, but differential, perhaps a warping and great faulting. On the western side of the Archipelago there is much evidence of this recent uplift, especially indicated by raised beaches and reefs, notably on the Ilocos and Batangas coasts, while on parts of the eastern coast, especially in the Paracale region, drowned river valleys are found. In the eastern half of the group, too, though not on the eastern coast, there are two great rivers, the Cagayan in northeastern Luzon and the Agusan in northeastern Mindanao, up which the tide runs for long distances. It seems to me that in spite of some local exceptions to this state of things, like the recent subsidence in Palawan, there has been a tilting of the

Philippine block toward the Pacific, perhaps a down drag as a result of the subsidence of the oceanic block into the Mindanao deep.

In the chapter on Seismology there is considerable detailed discussion of the tectonics of the Archipelago, but only a few general features will be considered here. Attention should be called to an early paper by Koto,(357) on the geologic structure of the Malay Archipelago, which is highly suggestive as to Philippine tectonics. In several details, I question Koto's interpretation; subsequent work, as might well be expected, has shown that on many points that he accepted from earlier workers his statements in the paper here cited will have to be revised. These, however, do not militate against the paper in its broader aspects. It should be understood also that Koto never visited the Philippines.

On the map (fig. 16) are shown the principal arcs, following Becker, and the relation of these structural lines to the seismic regions of the Archipelago as worked out by Saderra Masó and Smith. These arcs fall into two series; an inner one, northeast and southwest, and an outer one, northwest and southeast. There is in addition a north and south series of trend lines, not arcs, giving with the others a threefold system.

The most important arcs and tectonic lines in the Archipelago beginning with the innermost, to the west, are as follows:

The Palawan arc, which is continued into northeast Borneo. This may be a fault line and not an arc of folding at all. This line seems to be continued through the Taal area and may have some connection with the coast of Luzon northeast of Baler Bay.

The Cagayan arc, in the Sulu Sea.

The Jolo arc, which is continued through Zamboanga Peninsula and also passes through Cebu Island.

These three are the principal northeast and southwest trend lines. The northwest and southeast lines, including several that are nearly north and south, beginning at the west, are—

The Zambales line, through the extreme southwestern part of Luzon.

The Cordillera Central, running nearly north and south, as the backbone of Luzon. East of this, with a synclinal intervening, lies the Sierra Madre line along the east coast of Luzon. The Cordillera Central and the Sierra Madre line coalesce in Nueva Ecija Province in what is called by Adams the "Central Knot."

From the "Central Knot" a single line passes southeast through Tayabas Peninsula and the eastern prong of Masbate, thence through Leyte and down the eastern margin of Mindanao. Well to the eastward of this line, in the extreme eastern part of Luzon,

is the Camarines line; this, judging from the topography, runs more nearly east and west, but the strikes of schistosity were not east and west but northeast.

The three important points where these lines when projected appear to intersect are as follows: In southern Luzon, near Taal Volcano; in the northern part of Masbate, where there is an important gold field; in northwestern Leyte, where petroleum residues from seeps have long been known. A fourth possible junction is in the northern part of Mindanao, near Camiguin Volcano.

Whether or not there is any direct connection between these facts is not certainly known, but they are strongly suggestive.

Although the principal tectonic lines in the Archipelago are in general north and south, the inner line of arcs makes a pronounced curve * in the direction of Borneo, showing a tendency to fall in line with the principal tectonic lines of the rest of Malaysia which have in great part an east and west direction. It is seen, therefore, that the Philippines are a part of a region, including Java, Borneo, Sumatra, etc., which, with reference to Asia and Australia, occupies a position analogous to that of Central America and the Antilles with reference to North and South America; therefore, the region is one of great importance in the study of the geology of the Pacific. Prior to the Miocene there was undoubtedly sea connection with Europe by way of a greatly extended Tethys which reached from the Pacific to the Atlantic. Therefore, the deposits formed in this depression and the structures subsequently produced are of great interest and importance.

Becker, Koto, Hobbs, and others have pointed out the relation of the Philippine arcs to those of Asia, as delineated by von Richthofen.

As has been pointed out by Suess, and similar to what Omori has told us of Japan, and Andrews of Australia, the outer arc is one of closely folded rocks, and within this outer arc is a line of volcanoes such as Taal, Canlaon, and Camiguin. However, near the outer arc are two important cones that are active at intervals, Bulusan and Mayon.† The innermost arc consists of

* There is objection to the use of the words "curves" and "arcs" by some geologists who have studied the Philippine structure, but I agree with Becker in this generalization.

† Prof. W. H. Hobbs, who kindly read this chapter in manuscript, has indicated to me that the outer arc in the Philippine group is not the real outer arc toward the Pacific, but that this is to be found in the Marianne Islands, some 2,000 kilometers to the east of the Philippines.

folded rocks also, but with no sign of volcanism; at least, there is none at the present time. As in the Australian-New Zealand region, the outer arc is apparently the oil arc.

Practically all of the principal rock types are found in the Philippines. On a basement complex of igneous rock there are many thousand meters of sediments, mainly of Tertiary age, with some small outcrops of Mesozoic rocks, and these in turn are succeeded by lavas of the andesitic type, with great accumulations of more recent tuffs and considerable areas of coral limestone. Contrary to the former belief, the Archipelago is not dominantly volcanic, although active volcanism in recent years has been manifested at three rather widely separated points; namely, at Taal, 40 kilometers south of Manila; at Bulusan, in the extreme southeastern part of Luzon; and at Camiguin, off the northern coast of Mindanao.

The striking similarity between the formations in the Philippines and those of the west coast of America is another essential feature of the Philippine geology. The great basaltic and andesitic flows of the Pacific Northwest can be duplicated, if not in size, then in petrographic and structural characters, in this Archipelago. The radiolarian cherts of the California stratigraphic column have their counterpart in the Philippine Islands. Both later Tertiary faunas of the Philippines and the Eocene of California are tropical, with similar tropical genera. The statement is equally applicable to the Eocene of the Paris basin. The lithology of many of the formations on the two sides of the ocean is almost identical.

The geologic map (Plate 39) shows the distribution of the various formations. The reader is asked to bear in mind that this map is not accurate in details, since it is a compilation of material gleaned from books, manuscript reports, and the personal observations of engineers and geologists, in both Government and private service. The use of a certain pattern on a particular area of the map is intended to indicate the kind of rocks that are dominant within this area, and nothing more definite should be read into it. It will be seen that certain types of rocks predominate on the surface, at least in certain parts of the Archipelago; and it would seem that for a long time (for how many geologic periods cannot be stated) there have been archipelagic conditions here, judging from the many islands of igneous rock, the erosion of which has produced the covering of sediments that are now found about those primordial cores. Cutting through and in turn blanketing both sediments and

older plutonics are the more recent volcanics, which are localized, to an extent at least, along definite tectonic lines.

The deep-seated rocks are naturally not very widely distributed on the surface and usually are found only in the cañons of the central ranges, wherever the streams have cut through the overlying, more recent formations. They are particularly abundant in northern Luzon, throughout the Cordillera Central; in Palawan; the cordilleras of Panay; the central cordilleras of Cebu and Leyte; the eastern cordillera of Mindanao; and in Masbate.

In all parts of the Islands there is a large amount of extrusive material which forms a mantle over the deeper-lying formations. Naturally, these extrusions are found around the volcanic areas, and they are pronounced in the Zambales Range of southwestern Luzon and in various parts of the Cordillera Central, lying above the old igneous rocks and the Tertiary sediments. In the Cordillera Central there exist great patches of andesite, marking probably early Tertiary volcanoes. In the Zambales Mountains there is a development of andesite, indicating probably a still later period of volcanic activity. On Mount Arayat, which rises isolated out of the central plain of Luzon, basalt occurs, and around Taal Volcano and on Binangonan Peninsula there is a considerable amount of basalt. Extrusives are particularly well developed in the southeastern volcanic cluster of southeastern Luzon, comprising the well-known peaks of Bulusan, Mayon, Isarog, etc. They are found overlying much of Masbate, particularly in the central portion; also in western Panay; in a portion of Cebu; in most of northern Negros; in central Leyte; and, notably, in Mindanao, a broad belt of extrusives running north and south through the Apo and Matutum Ranges. There is a great patch of basaltic material around Lake Lanao, and Mount Malindang is the center of a great volcanic mass. There is also great development of these extrusives covering almost the entire islands of Basilan and Jolo and the lesser islands of the Sulu Archipelago. As yet we know of extrusives in Palawan in only its northern part. The principal mountainous mass of Mindoro, Mount Halcon, is largely andesitic. My earlier statement, that "the entire recent volcanic activity consists, as far as we know, of basaltic materials," was too sweeping and should be modified. Much of the ejecta from Taal during the last eruption was basaltic, but andesitic material was also thrown out. Much of the recent ejecta (I know of no recent lava flows in the Philippines) from Mayon is scoriaceous basalt, as is also that from Canlaon Volcano.

The material which poured down the side of Bulusan in a recent (1915) eruption was classed by Goldsberry as andesitic.

Large and small laccoliths of diorite, granite, and peridotite are innumerable throughout the Islands. In the Cordillera Central the intrusions seem to be generally diorite and quartz diorite. They cut both the Tertiary sediments and the overlying extrusives in some cases. In the Camarines region, granitic intrusions cutting the diorite and possibly the sediments can be seen.

In Sulu Archipelago I have found a number of small basaltic intrusions cutting some of the recent sediments. Owing to the absence of an accurate base map of the Philippines and the fact that my work has been largely of a reconnaissance nature, these intrusions have not been mapped in detail, or with sufficient accuracy to allow me to state whether or not they follow any general system of jointing or earth lineaments, though they seem to do so.

Flanking all the cordilleras on both slopes there is a greater or lesser development of sandstones, shales, and limestones which have been bowed upward in the Miocene and later uplifts with some minor crumpling at various points and, of course, accompanied by much faulting. The folding in northern Luzon in many places has apparently been a gradual and gentle uplift of the strata. In Tayabas Peninsula the flexures are sharper. In Zamboanga Peninsula the strata have been so intensely compressed that schists are the result. These schists have been considered by some to be older than the Tertiary, but there seems to be no good reason for not referring them, in part at least, to the Tertiary. The central portion of Mindanao consists of folded sediments and intrusives. The major axis of folding in the Philippines is in general north and south; along the outside arc of the Islands, northwest and southeast; on the inside, northeast and southwest.

Metamorphic rocks occur more or less pronouncedly in various parts of the Islands. In Ilocos Norte there is a considerable development of schist, and in the Camarines region are schist and gneiss along the border of the granite intrusion referred to above. Schists have been found at several localities in the central cordillera of Cebu; at various points in Palawan; on Zamboanga Peninsula, referred to above; in Bukidnon Province, Mindanao; on Surigao Peninsula and just east of Davao Gulf; at one point on Tayabas Peninsula; and on Caramoan Peninsula, southeastern Luzon. The schists appear to be for the most

part metamorphosed sediments, although many are undoubtedly derived from basic igneous rocks.

Recent alluvium from the mountains deposited upon coral shelves has resulted in a greater or lesser development of coastal plains around many of the islands. The coastal plains are negligible, with the exception of the Occidental Negros plain, but some of the intermontane plains are very important. The northwestern part of the central plain of Luzon is largely alluvium. The Albay plain is also largely alluvium, as are the great valleys of Cagayan, Agusan, and Cotabato Rivers. Also, the central plain of Panay shows a very considerable accumulation of detrital material.

Around Manila there is, in addition, a great area of pyroclastic material which is cut through by Pasig River. This is known from well logs and river sections to be at least 300 meters thick.

GEOGRAPHY

POSITION OF THE PHILIPPINES RELATIVE TO OTHER COUNTRIES

The Philippine Islands are situated about 800 kilometers from the Asiatic coast between 116° and 127° east longitude and between 4° 30′ and 21° 30′ north latitude. On the north is Formosa; on the southwest lies Borneo.

The important world position of the Philippines and of Manila, the capital, is shown on the map (fig. 1). The Philippines bears the same relation to Malaysia as Japan does to northern Asia, and England to the continent of Europe. The position of the

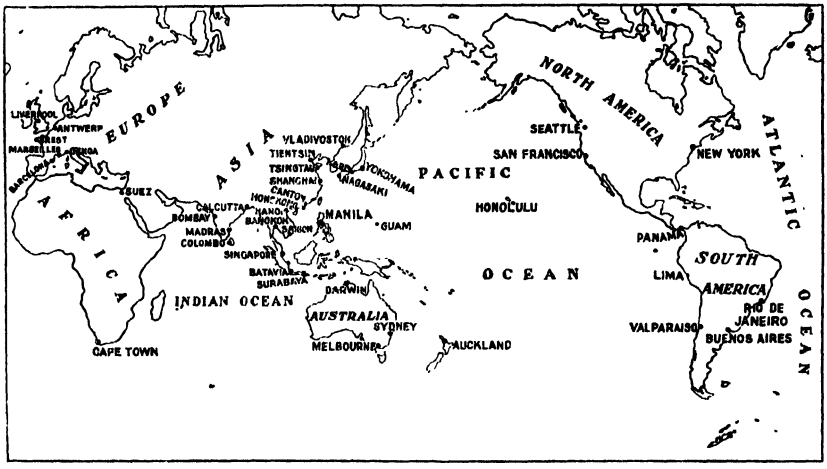


FIG. 1. Map of the world, showing the central position of Manila in the Far East.

Islands with reference to the United States and the rest of Malaysia, with the impetus received from the United States, ought to give them a commanding position in the future commerce, culture, and politics of this region.

There are over seven thousand islands and islets in the Archipelago. The largest is Luzon, with an area of 104,880.24 square kilometers; Mindanao is next; then Samar, Negros, Palawan, and Panay.

The highest mountain, Mount Apo, in southern Mindanao, is 2,929 meters in height. The largest river is the Cagayan, in northern Luzon, 352 kilometers long. The largest city is Manila, with 300,000 inhabitants. The next cities are Cebu and Iloilo.

HISTORY OF PHILIPPINE EXPLORATION AND CARTOGRAPHY

Up to 1521, the Philippine Islands remained unknown to western peoples, although the Chinese traded here long before the coming of the white man.* In that year the intrepid Magellan began his long cruise around the world. He touched first Mindanao, or Homohon, and later Cebu, one of the lesser islands of the group. Magellan landed and unwisely took part in a feud then raging between the people of Cebu and the inhabitants of Mactan, and on a spot now marked by a beautiful coral-stone monument, in a coconut grove by the sea, he met his death. His ship, *Elcano*, with what was left of the valiant crew, sailed away to complete the first circumnavigation of the globe, to announce to the world the death of a hero, and to tell of the wonderful isles of the East.

I shall not attempt to mention all of those who have done exploratory work in the Philippines, but will give the names of the most important. The British Admiralty, in accordance with its policy of developing commerce, has done considerable work in these waters, particularly along the coast of Palawan, and has published a series of general and harbor charts of the Islands. One of the earliest of the British explorers in this region was William Dampier, who discovered the Batanes group in 1687. He called them the Bashi Islands, after a local drink of that name. One of the first works in the English language pertaining to the geography of the Philippines was by James Horsburgh, F.R.G.S.(328) In 1843 to 1846, Capt. E. Belcher, R.N., commanded H.M.S. *Samarang* on a voyage through the eastern seas, where important explorations were made. He visited the Philippines. In 1883 occurred the cruise of the yacht *Marchesa,* commanded by Lieut. R. Powell, R.N. The narrative of this voyage was written by F. H. H. Guillemard, M.D. The most important contribution from this voyage was a map of Cagayan Sulu, a small island in Sulu Sea, noted for its volcanic

* Dr. H. Otley Beyer, professor of anthropology in the University of the Philippines, has recently published some interesting accounts of Javanese colonization in the Philippines which antedate the coming of Magellan. These accounts have appeared in the periodical Asia.

craters and hot spring. The *Challenger*, which visited the Philippines in the latter part of 1874, did not do much work of a geographic nature. Most of the time was spent in making zoological collections along the shores of the Islands. Another hardy Briton to touch the Philippines was Capt. Thomas Forrest. The voyage extended over the period from 1774 to 1776.(282) Forrest was at that time in the employ of the East India Company. Some old prints in his book are probably among the earliest charts of the shores of Mindanao. In 1880 the British survey ship *Flying Fish* was still engaged in coast-survey work in the vicinity of Palawan and Borneo.

Of the long procession of navigators and geographers sent out from Spain in the three hundred years of that country's domination, Urdaneta, who was Legaspi's navigator, must be accorded seniority. It will be remembered that Legaspi founded Manila in 1571.

Coming now to a discussion of the Spanish work, we find a long and interesting story, and one reflecting great credit upon a nation of magnificent explorers. As elsewhere, we find the missionaries in the lead. There have been in the Philippine Islands, at one time or another, six large religious orders; namely, the Franciscans, the Dominicans, the Augustinians, the Recoletans, the Capuchins, and the Jesuits. Each of these bodies has contributed to the mass of valuable geographic knowledge information which would have been much more tardy in coming forth but for these intrepid apostles of Christianity.

Perhaps the most active of these have been the Jesuits. For a long time we were indebted to the members of that order for almost all the reliable information regarding the mysterious and wild island Mindanao, which was practically under their control for years. When the American Government came to take an inventory of its new possessions, the Jesuits had a large collection of maps of the various islands. These were turned over to the Philippine Commission and published by the United States Coast and Geodetic Survey.(624) This atlas contains thirty maps, of which eleven were executed by Enrique d'Almonte, one by Enrique Abella, one by the Hydrographic Commission, and three by the Jesuits. The remainder were compiled from British Admiralty charts and other sources.

D'Almonte was the foremost of those engaged in map making during the Spanish régime. His maps, in most cases not based on any accurate control, are simply wonderful when the character of the country traversed and the extent and execution of the

work are considered. Certainly no other man in the Philippines, either before or since, has accomplished so much in this line. Enrique d'Almonte was attached to the mining bureau, with the title *auxiliar facultativo*, which simply means "scientific assistant." He and Enrique Abella y Casariego, the chief of the Cuerpo de Ingenieros de Minas, constantly worked together, d'Almonte as topographer, and Abella as mining engineer and geologist. Considering the natural difficulties of the country, the extremely primitive people that exist in some parts of the Islands, and the very trying climatic conditions, d'Almonte must be regarded as one of the great explorers of this part of the world. Whether or not he has ever received fitting testimony or appreciation from his fellow geographers in other parts of the world is not known; if he has not, recognition should be soon forthcoming. D'Almonte died in 1918 while returning to Spain from a brief visit to the Philippines.

I must not omit to call attention to the magnetic surveys made in Mindanao by the Jesuits. One important feature discovered is that there is a close connection between the magnetic declinations and Agusan Valley, one of the principal tectonic lines of the island.

A map by M. Sanson d'Abbeville * is, as far as I know, the earliest map of these Islands. There is a copy in the archives of the Dominican Monastery in Manila. The second and probably the most important contribution is that of Dr. J. Montano, who visited the Philippines and traveled rather extensively in the Islands during 1879 to 1881. Montano spent a large part of his time in Mindanao; and with Rajal, then governor of Davao, he made the first ascent of Mount Apo of which we have any record. When I ascended Mount Apo in 1907, I found near the summit a baked-clay tablet bearing the inscription:

LA ÚNICA EXPEDICIÓN A VOLCÁN APO
1880
MONTANO Y RAJAL.

Montano was also one of the first men to travel from Davao up Tagum River, over the divide, and down Agusan River to Surigao. He also made many valuable anthropologic, ethnographic, social, and economic studies, which have been published by the department of instruction of the French Government.

Among German explorers, the two most conspicuous were Semper and von Drasche. The former explored in the Philip-

* Les Iles Philippines, Molucques, et de la Sonde. Paris (1654).

pines for over three years about 1860, and the latter during five months in 1876.

Semper was a zoölogist and his geologic collections were worked up by others, but von Drasche's contributions were chiefly geologic, most of them published under his own name. (200)

The work being done under the American régime is rather heterogeneous, but complete. The following Government units are at present engaged in mapping, for one purpose or another, various portions of the public domain: The United States Army, the Bureau of Coast and Geodetic Survey, the Bureau of Constabulary, the Bureau of Lands, the division of mines of the Bureau of Science, and the Bureau of Forestry. The basal work and the most accurate is that done by the Coast and Geodetic Survey. In order best to show what that organization has done, a memorandum is here included which Mr. E. R. Frisbie, acting director (in 1921), Bureau of Coast and Geodetic Survey in the Philippines, especially prepared for me.

TABLE 1.—*Work of the Coast and Geodetic Survey in the Philippines.*

Area within the boundaries of the Philippine Islands, taking the treaty limits (approximately) (square statute miles)	700,686
Land area of Philippine Islands (square statute miles)	115,026
Water area within boundaries (square statute miles)	585,960
Length of general coast of the Philippine Islands (statute miles)	11,511
Triangulation:	
Stations occupied	3,000
Area covered (square miles)	97,000
Geographic positions determined	7,500
Azimuth stations occupied	42
Base lines measured	73
Magnetic stations	132
Topography:	
Detailed coast line surveyed (miles)	15,887
Topographic sheets surveyed	732
Hydrography:	
Area sounded (square miles)	154,825
Hydrographic sheets surveyed	755
Soundings made	5,234,845
Tidal stations	338
Steamers employed	4
Officers and men on steamers	243
Officers and men in office	47

According to Capt. E. F. Dickens, former director of the Bureau of Coast and Geodetic Survey—

> Active work was commenced in the Philippines in December, 1900. A suboffice was established in Manila and two vessels were equipped for the work, the steamer *Pathfinder* by the Federal Government and the steamer *Research* by the Insular Government. The United States pays about 65 per cent of the expense, supplies one large steamer, all the technical force in the field, the supervising technical force in the Manila office, all the instruments and outfit, and meets the entire cost of the final revision and publication of the charts, tide-tables, sailing directions, and other results. The Insular Government defrays about 35 per cent of the cost of operation, furnishes four steamers, and keeps them in repair and supplies the office accommodations in Manila.

Obviously the Bureau of Lands was created for the purpose of making cadastral surveys. Besides making innumerable patent surveys for mineral claims and forest concessions, it has had the large task of surveying the great estates known as the Friar Lands.

Besides this mass of routine labor, the Bureau of Lands has found time to extend its functions and to begin some important work of a much greater scope. In this work, which will be outlined more fully below, two men have been most active; namely, S. O. Scudder, chief surveyor, and Charles Benson. The last American director of the Bureau of Lands, Capt. Charles H. Sleeper, with his assistants elaborated a general plan for extending our exact knowledge of the Islands, and work on this has been successfully begun.

Soon after the conclusion of the Spanish-American War the United States Army began systematic topographic mapping all over the Islands.

The Bureau of Constabulary, which is the Insular police organization, is also doing considerable serviceable map work.

The division of mines of the Bureau of Science is the lineal descendant of the mining bureau of Spanish days. It is the function of this organization—

> * * * To make, facilitate, and encourage special studies of the mineral resources, mineral industries, and geology of the Philippine Islands; to collect statistics concerning the occurrence of the economically important minerals, and the methods pursued in making their valuable constituents available for commercial use; to make collections of typical geological and mineralogical specimens, especially those of economic and commercial importance, such collections to constitute the museum of the Mining Bureau, subject however to transfer by executive order of the Civil Governor to any general museum established; to provide a library

of books, reports, drawings, etc., bearing upon the mineral industries, the sciences of mineralogy and geology, and the arts of mining and metallurgy, such library constituting the library of the Mining Bureau [now division of mines of the Bureau of Science]; to make a collection of models, drawings, and descriptions of mechanical appliances used in mining and metallurgical processes; to preserve and maintain such collections and library so as to make them available for reference and examination and open to public inspection at reasonable hours; to maintain in effect a bureau for information concerning the mineral industries of the Philippine Islands; to make an annual report to the Secretary of the Interior [now Secretary of Agriculture and Natural Resources], setting forth the important results of the work of the Bureau, such special reports as may be called for by proper authority, and such bulletins concerning the statistics and technology of the mining industries and of the geological and mineralogical and other office and field work of the Bureau as may be approved by the Chief of the Bureau and ordered published by the Secretary of the Interior.

Some idea of the work accomplished by this organization can be obtained from Table 2 and from the Bibliography.

TABLE 2.—*Maps issued by the Spanish mining bureau and the Division of Mines, Bureau of Science, from 1886 to 1914.*

No.	Name.	Geologist.	Date.	Scale.
1	Cebu Island	Abella	1886	1 : 100,000
2	Panay Island	do	1890	1 : 200,000
3	Mankayan-Suyoc (Luzon)	Eveland	1905	1 : 24,000
4	Batan Island	Smith	1905	1 : 24,000
5	Compostela-Danao (Cebu)	do	1906	1 : 24,000
6	Baguio (Luzon)	Eveland	1907	1 : 24,000
7	Aroroy (Masbate)	Ferguson	1909	1 : 20,000
8	Mindanao Island	Smith	1910	[a] 1 : 750,000
9	Southwestern Luzon	Adams	1910	1 : 400,000
10	Southeastern Luzon	do	1911	1 : 400,000
11	Bondoc Peninsula, Tayabas (Luzon)	Pratt	1913	1 : 60,000
12	Philippine Archipelago	Smith and others	1913	[a] 1 : 4,000,000

[a] Approximate.

The Bureau of Science, of the Government of the Philippine Islands, consists of divisions of mines, chemistry, biology, botany, entomology, ornithology, and fisheries. Reports of practically all the scientific results secured are published in the Philippine Journal of Science, which is now (1921) in its sixteenth year.

Besides the Bureau of Science, special mention should be made of the Bureau of Forestry and the Bureau of Agriculture, which are making forestry and soil maps, respectively, of the public domain.

The contributions to the geology of the Archipelago made by the division of mines and others are listed in the Bibliography.

Until 1913, most of the scientific work of the Government was directed by the Department of the Interior. This work is now under the Department of Agriculture and Natural Resources.

Regions still little known geologically and geographically include the central portions of Mindanao lying south of Kabakan River and between Lake Lanao and Agusan River; central Mindoro; the Sierra Madre Mountains, in Isabela and Cagayan Provinces, northeastern Luzon; and Palawan Island.

RECOMMENDATIONS FOR FUTURE WORK

First, a topographic map of the whole Archipelago should be begun. At the present time the Coast and Geodetic Survey and the United States Army have undertaken more or less of this work. However, the Army work is not generally available; nor is it always done according to the ideas of the geologist, but rather and more especially for the purpose of recording military features, and much of the work covers country that at the present time is of little or no interest to the geologist and the mining engineer. To make a general topographic survey of the Philippine Islands would require at least twenty-five years and perhaps as many million pesos. Furthermore, real geologic mapping by quadrangles or provinces should be undertaken at an early date. In the past the geologic work has been centered around some particular mining camp, and it has not been possible to carry on the work uniformly over considerable areas.

Specialists from the United States should be brought to the Islands for work on special problems, but a permanent staff to coördinate the work in the Philippines should be maintained in Manila. It would be highly desirable to have both the financial and the technical coöperation of the United States Geological Survey.

The geologic problems in the Philippines are by no means local, and much of the geology of the Pacific region will have to be interpreted with reference to the geologic results obtained in the Philippines.

CLIMATE, POPULATION, FLORA, AND FAUNA

CLIMATE

The Jesuit Fathers of the Philippine Weather Bureau have published reliable and voluminous literature on the climate. Particular mention should be made of the papers (123) by José Algué, director of the Philippine Weather Bureau, and by José Coronas, chief of the meteorologic section of the same bureau.

Only in recent years, chiefly through the work of Huntington,* has a true appreciation of the rôle of climate been brought about. Changes in climate have completely altered and in time caused civilizations to disappear. Although the effects of Philippine climate have been often overstated and misstated, it must be admitted that, for the white man at least, the climate is not conducive to most-efficient work nor to greatest comfort, and for certain types of individuals it is positively harmful. Even the Filipino, accustomed by centuries to the heat and protected by the pigment of the skin, shows the effects. The well-known running amok of certain Malays, while often started by religious fanaticism, can, it is believed, be attributed to an overwrought condition of nerves induced by climatic conditions. It is well known that white men become more irritable in this climate than they would under normal conditions in temperate regions. Americans commonly make the mistake of expecting too much from laborers in the Tropics. No one ought to do outside manual labor between noon and 3 o'clock in the afternoon. More can be accomplished by resting during the middle of the day.

From paleontologic studies it appears that throughout the Tertiary and Recent periods there has been no essential change in climate in this part of the world.†

To get a clear idea of the climate of the Philippines we must bear in mind the relation of the group to Asia and to the Pacific Ocean and the topography of the group itself.

According to Supan's climatic map, the Philippines are in the Indo-Australian monsoon region; but, according to the Philippine Weather Bureau, the southwest monsoon does not exist in the Philippines. The so-called "northeast monsoon" is merely

* Climate and civilization. Yale University Press (1915).

† Dickerson believes that the Japanese current was persistent during the Pleistocene, as Pleistocene reef corals flourished upon the Riu Kiu Islands as far north as 29° 30′. On account of this warm current the effects due to glaciation with the consequent cooling of tropical waters were completely damped.

the trade wind. Nevertheless, the proximity to the Asiatic mainland undoubtedly does modify the climate of the Philippines. The seasons in the Philippines are primarily due to the shifting north and south of the trade-wind belt in the Pacific.

Although the Philippines are near the equator, the heat is tempered by the ocean breezes, and living conditions are greatly ameliorated thereby.

As the Archipelago presents great topographic diversity, with prominent cordilleras having several points between 2,550 and 2,850 meters in altitude, the climate in various portions of the group is considerably modified. For instance, in the highlands of Luzon (elevation about 1,500 meters), where the principal gold camp is located, the climate is very much like that of Asheville, North Carolina, in the United States, and the conditions are those of the North Temperate Zone.

In general, the Philippines may be said to have three types of climate, as follows:

First type.—Two pronounced seasons, dry in winter and spring and wet in summer and autumn.* This type occurs in the western half of Luzon and along a narrow belt in Mindoro, Panay, Negros, and Palawan.

Second type.—No dry season, with a strongly pronounced maximum rainfall in winter. This is found prevailing along the eastern border of the Archipelago from about the latitude of Manila south; that is, in southeastern Luzon, Samar, the eastern half of Leyte, and Surigao Province, Mindanao.

Third or intermediate type.—The third type is divided into two subtypes. There is no very pronounced rain period in this type, and the area embraced is, in general, all that is not included in the first and second types; that is, Cagayan Valley, the central portions of the Visayas, and western Mindanao.

The average annual rainfall for the Archipelago is 2,366 ± millimeters (about 94.6 inches). The greatest annual rainfall, 9,038.3 millimeters, was recorded at the Baguio weather station in the highlands of Luzon, in 1911. The greatest rainfall at Baguio for a single period of twenty-four hours was 1168.1 millimeters (46 inches); this is perhaps a world record.

The mean annual temperature for the Archipelago deduced from all stations near sea level is 26.9° C. (80.4° F.). The figures from high stations are not included.

* It must be remembered, of course, that no well-defined seasons like those of winter and summer in the temperate regions exist in the Tropics.

The hottest months are April and May; January is the coolest. The absolutely highest temperature of Luzon is 42.2° C. (108° F.), and the lowest 11.8° C. (53.7° F.). The range in other parts of the Islands is not so great.

Humidity.—The humidity of the Philippines is high, due to the proximity to the sea, the great rainfall, and the richness of the vegetation. Of course the last of these is also an effect of humidity, but the excessive vegetation acts as a sponge which retains moisture and in this way keeps the humidity high. The highest mean annual humidity is that of Baguio; the lowest is that of Cebu. The annual means of thirteen stations from widely separated localities vary between 76.7 and 85.7 per cent. The mean annual humidity of Manila is 80 per cent. Compare this with that of Seattle, Washington, in the United States, which is 76 per cent.

Although the mean temperature of the Philippines is rather high, the temperature rarely exceeds 37.8° C. (100° F.), but the high humidity coupled with even moderate heat is oppressive. However, the sea breezes greatly moderate the temperature. This, and a considerable amount of cloudiness during the summer months, in certain parts of the Archipelago at least, give the Philippines a climate much superior to that of many other parts of Malaysia.

Winds and storms.—Sufficient mention of the ordinary winds in this region has for our purposes already been made. It remains to give some attention to the storm characteristic of this region and known as the typhoon or, locally, baguio. This storm is nothing more than a tropical hurricane and, contrary to common opinion, is hardly any more severe than the Gulf hurricane of the United States. However, typhoons are destructive enough and must be reckoned with by those who are engaged in engineering, construction, and transportation. For example, the severe typhoon of 1909 in the highlands of Luzon caused the complete destruction of the Benguet Consolidated Company's gold mill and serious caving in the mine. Dredges have been sunk, railroad tracks washed away, and much minor damage has been done so often that it is imperative that typhoons be understood and guarded against.

Briefly, typhoons are cyclones revolving counterclockwise, which form over the Pacific Ocean, as a rule east of the Ladrone Islands, and move westward and then northwestward; a few typhoons swerve northward and northeastward. Most of the

typhoons pass across or close to the Philippines. Of those that pass across the Archipelago, practically all pass north of Mindanao, and the majority strike Luzon. These baguios are characterized by very low barometer, very gusty and intermittent high winds, and deluges of rain. The lowest barometer ever recorded, with one exception, was during one of the worst of these storms to occur in late years (September, 1905), when the center of the storm was directly over Corregidor Island at the entrance of Manila Bay and the barometer fell to 690.1 millimeters.* The maximum wind velocity at that time was 165.7 kilometers (103 miles) an hour.

Thunder storms.—Thunder storms with lightning, in the lowlands at least, are not uncommon.

Cloudiness.—As the degree of cloudiness has close connection with the question of light, which will be discussed next, it is well to note a few facts with relation to it. According to Algué, the mean cloudiness for the year at Manila, on a basis of 10 (the sky being entirely covered) is 5.6. The cloudiest month is September, and the brightest is April.

Light.—The late C. E. Woodruff, who served some years in the Philippines, studied the effects of tropical light.† Although some of his conclusions will have to be modified, the main contention that tropical light, through the action of infra-red rays of the sun, causes overstimulation and in time produces neurasthenic symptoms in persons who have a deficiency of pigment in the skin has not yet been disproved. Woodruff recommends that brunettes only be sent to the Tropics, and that blondes ought not to remain there long.

Freer and Gibbs worked on tropical sunlight, and their experimental data seem to indicate that tropical sunlight does not materially differ from the sunlight in other latitudes.‡

Barometric pressure.—The statement is made in one of the foremost textbooks on geology § that—

> Ascending atmospheric currents, with low barometer, high temperature, air saturation, excessive precipitation, and lowering skies tend to physical and intellectual lassitude and inactivity.

* During the typhoon which crossed the Babuyanes in 1913 the barometer on the steamer *Empire* recorded 683.17 millimeters.

† The Effect of Tropical Light on White Men. New York and London, Rebman Co. (1905); Blondes and brunettes in the Tropics, N. Y. Med. Journ. (1912).

‡ Philip. Journ. Sci. § B 5 (1910) 1; 7 (1912) 1.

§ Chamberlain and Salisbury 3 (1907) 535.

This is in the main correct, but I have been unable to find much discussion relating to barometric pressure and its effects in the Tropics. According to Saderra Masó, the normal yearly barometric pressure at Manila is 760 millimeters (29.9 inches), a little lower than that in temperate regions, but with less variation during the year. Huntington * has produced some very definite and convincing data on this subject as relating to the temperate regions, but no investigation of this kind seems to have been made in the Tropics.

Tropical climate is complex and is an important item to be considered by those who expect to live and work in the Philippine Archipelago.

POPULATION

The best information available with regard to the number and composition of the Philippine population is that given by H. Otley Beyer,† head of the department of anthropology of the University of the Philippines, Manila. The following facts and figures are from his publication:

Total population, 10,000,000 + 43 ethnic groups.
Race types:

1. Pygmies, pagans—
 1. Negrito.
 2. Proto-Malay.
 3. Australoid-Ainu.
2. Indonesians, pagans (Igorots, etc.). Taller; affinities with certain races of southern Asia.
3. Malay, brown-yellow, shorter than Indonesians—
 1. Pagans.
 2. Mohammedan.
 3. Christian.

Over eight millions of the population comprise the civilized and semicivilized lowlanders. The dominant groups are the Tagalog, Visayan, Bicol, Ilocano, Pampangan, and Pangasinan. These are practically all Christians and are either pure Malays or Mongoloid and Indonesian blends.

About 8,000,000 are Christians; 315,000, Mohammedans; and 700,000, pagans; 73,000 are foreign born, of various religions, mostly Christians; 50,000 are Chinese.

There are about sixty-eight dialects, of which twenty-six have a printed literature. Tagalog, Visayan, and Ilocano, which are all related to Malay, are the dominant dialects. Spanish is

* Climate and civilization. Yale University Press (1915).
† The Population of the Philippine Islands. Manila (1916).

spoken by most of the older lowland peoples, whereas English is used by the young generation in an increasing degree; the hill people as a rule use neither.

The Filipinos are largely an agricultural people. The Chinese are the dominant traders in the Islands. Japanese are immigrating in greater numbers than any other race.

FLORA *

The Philippine flora is a very rich one, approximately 10,000 species of flowering plants and ferns being known from the Archipelago. The flora is in general essentially Malaysian, its chief alliances being with that of the Malay Archipelago, but with distinctly continental (Himalayan) elements in the mountains of northern Luzon, and a small but very interesting series of Australian types occurring at both lower and higher altitudes. The flora is further characterized by a comparatively small percentage of endemic genera and a very high percentage of endemic species, the specific endemism approximating 60 per cent. This probably indicates geologic separation from surrounding countries for a sufficiently long period of time to account for the development of the very high percentage of endemic species, but not a sufficiently long period of time to allow for the development of many endemic genera.

In general the dominant species along the seashore, in the settled areas at low altitudes, in the vast areas of open grassland, and in the secondary forests are identical with widely distributed Indo-Malaysian forms occurring in similar habitats over the vast Indo-Malaysian region. In the primary forests, however, the dominant species are, for the most part, endemic. The percentage of endemism is very low in the settled areas at low altitudes, in the open grasslands, and in the secondary forests, indicating destruction of the original primary forests and replacement of endemic species by introduced forms. The vegetation of the coastal regions, the settled areas, the open grasslands, and the secondary forests should be largely ignored in drawing conclusions as to the origin of the Philippine flora.

The settled areas, except for the cultivated plants, are characterized by a predominance of introduced weeds, mostly of pan-

* This section on the Flora is contributed by Elmer D. Merrill, director and botanist of the Bureau of Science.

tropic distribution, and various introduced trees and shrubs with comparatively few endemic species. The vast areas of open grassland are characterized by the dominance of lalang grass (cogon), talahib (*Saccharum*), *Themeda,* and other coarse grasses, probably due to the activities of man. The original forest is cleared from small areas which are cultivated for a few years, but under primitve agricultural conditions these clearings are usually quickly occupied by coarse gregarious grasses with which the primitive agriculturist is unable to cope. The vegetation of the coastal areas, including the mangrove swamps, is practically identical with that of similar areas throughout the Malay Archipelago or, for that matter, throughout the Tropics of the Old World.

The primary forests at low altitudes are characterized by a very large number of tree species, between 2,500 and 3,000 species of trees being known from the Archipelago. Many of these, especially the dominant Dipterocarpaceæ, including such commercial timbers as lauan, apitong, mayapis, yacal, tangile, etc., attain a very large size. Nowhere in the Philippines, except in the pine regions of Luzon and Mindoro—and there chiefly in the mountains at medium and higher altitudes—and in the mangrove swamps about mouths of tidal streams do we find gregarious forests; that is, forests composed chiefly or entirely of a single species. The average primary forest in the Philippines somewhat closely approximates the mixed deciduous forests of temperate countries, but is vastly more complex.

At higher altitudes in the Philippines the character of the forest radically changes. The species dominant at lower altitudes disappear and are replaced by representatives of other genera. On the mountains we find numerous representatives of groups more or less characteristic of the North Temperate Zone, such as oaks, rhododendrons, huckleberries, and other temperate types. The mossy forest which characterizes the higher mountains of the Philippines, usually commencing at an altitude of about 800 meters, is composed of a very large number of species of trees and shrubs. The trunks and branches, and the earth as well, are covered with a highly developed moss flora, accompanied by numerous ferns, epyphitic orchids, and some herbaceous plants.

In number of known species the family Orchidaceæ is by far the largest in the Philippines, between 850 and 900 species of this group being now known. The next largest group is the

Polypodiaceæ, a family of ferns; but the entire group of ferns and fern allies presents more known species in the Philippines than does the family Orchidaceæ. Among the families of flowering plants other than the Orchidaceæ the most highly developed ones in the number of species are the Rubiaceæ, the Euphorbiaceæ, the Myrtaceæ, the Moraceæ, the Leguminosæ, and the Gramineæ, in approximately the order named. Other large families are the Palmæ, the Urticaceæ, the Anonaceæ, the Lauraceæ, the Meliaceæ, the Sapindaceæ, the Guttiferæ, the Dipterocarpaceæ, the Melastomataceæ, the Sapotaceæ, the Apocynaceæ, the Gesneraceæ, and the Verbenaceæ.

FAUNA *

The Philippines, politically speaking, and the Philippines, zoölogically speaking, as has been shown by Worcester, are not identical areas, Balabac, Palawan, and the Calamianes being characterized by the occurrence of numerous Bornean forms which are conspicuously absent from the remaining islands. Although the Philippines are commonly held to form a northeastern extension of the Indo-Malaysian subregion, there is a large amount of specialization in the fauna of the islands lying to the east of the Palawan group.

Mammals.—Mammals are scarce, with the exception of shrews, rats, mice, and bats. No marsupials occur. The edentates are represented by the pangolin (*Manis javanica* Desmarest) of the Palawan group. In the seas are found the dolphin, cachalot, and dugong. Wild hogs of at least two species occur. The beautiful axis deer of Sulu (*Melanaxis*) has apparently been brought there by man. Red or brown deer (*Rusa*) occur in Basilan, Mindanao, Leyte, Samar, and the Calamian Islands. The number of species and their respective ranges have not been satisfactorily determined. The mouse deer, or chevrotain (*Tragulus nigricans* Thomas), is found in Balabac and Palawan and is one of the mammalian curiosities of this region.

The most interesting of the ruminants is the timarau (*Bubalus mindorensis* Heude), peculiar to Mindoro. Unlike the water buffalo, it does not bathe in water or wallow in mud. It is extremely wild, feeding by night and sleeping by day in the densest jungle.

* The abbreviated material for this section is based upon the article in the 11th edition of the Encyclopædia Britannica, but has been completely revised by specialists in the Bureau of Science.

Squirrels are found in Balabac, Basilan, Mindanao, Samar, Culion, and Palawan.

Among the carnivores are mongooses (*Mungos palawanus* Allen and *M. parvus* Jent.), the binturong (*Arctictis whitei* Allen), an otter (*Aonyx cinerea* Illiger), found in the Palawan-Calamianes group; civet cats (*Viverra* and *Paradoxurus*), which range throughout the Archipelago, and a wildcat of small size (*Felis minuta* Temminck) known also from Java. Bats are very numerous; at least fifty-six species are recorded, many of them peculiar to the Philippines. The flying lemur (*Cynocephalus volans* Linn.) and tarsiers (*Tarsius* spp.) range from Basilan to southern Luzon. Large fruit bats (*Pteropus*) occur in immense colonies and are sometimes used as food. In spite of all that has been said to the contrary, only one genus of monkeys (*Pithecus*), represented by five species, has been discovered in the Philippines.

A porcupine (*Thecurus pumilus* Günther) occurs in Palawan, Balabac, and the Calamianes.

Especial importance attaches to the unexpected discovery by Whitehead of a peculiar mammalian fauna, inhabiting a small plateau on the top of Mount Data, in northern Luzon, at an altitude of nearly 3,000 meters. Specimens of fifteen species were obtained, embracing five new genera (*Celaenomys, Chrotomys, Rhynchomys, Batomys,* and *Carpomys*). Eight of the species were new and strikingly peculiar. Their zoölogical relationships are probably with Celebes and Australia. Mearns also found a considerable number of peculiar, small mammals on Mount Apo, Mindanao. Other discoveries include a few new squirrels and bats, and a slow lemur (*Nycticebus menagensis* Lydekker) in Tawitawi.

Cattle are raised on most of the islands. They are grown for their flesh, hides, and horns, and little attention is paid to their milk-giving properties. The water buffalo, or carabao, occurs in a wild state in Luzon, Mindoro, the Calamian group, Masbate, Negros, and Mindanao, but the wild herds are believed to have originated from domesticated animals.

Birds.—There are about 760 species of birds known from the Islands. These show rather strong relationships to the birds of Borneo, and a lesser relationship, but in some cases more striking, to those of Celebes and New Guinea. The birds of the small islands north of Luzon show some relationships to the birds of Formosa. A large number of the species are en-

demic; that is, they are confined to the Philippine Islands and many of them are confined to a few or to single islands. The generic endemism is over 12 per cent, and the specific endemism, over 73 per cent. The jungle fowl, or wild chicken, is found in all of the larger islands. There are many species of pigeons and doves. Two families of birds that are not ordinarily thought of as game birds, the parrots and the hornbills, are fairly conspicuous in the larger islands.

Reptiles, batrachians, and lizards.—Reptiles and batrachians are abundant, but have been little studied. Pythons occur throughout the group, and some attain a length of 10 meters. There are numerous venomous serpents, but the mortality from snake bite is comparatively low. The lizards include geckos, several introduced house lizards, and monitors. Geckos may be seen on the walls and ceilings of any house. Flying lizards (*Draco*) occur in the forests.

Fishes.—The marine fauna is one of the richest and most varied in the world. More than a thousand species of fishes are already known, of which at least three-fourths are used as food. The fresh-water fish fauna is relatively unimportant, and is mostly composed of marine fishes which have recently occupied the streams. The exclusively fresh-water species belong almost entirely to the Siluridæ, or catfishes; the Cyprinidæ; and those amphibious fishes which seem almost equally at home in mud or on land and in water, the Anabantidæ, or climbing perches; and the Ophiocephalidæ, or mudfishes. Fishes of the last two families make their way into the rice fields and meadows during the rainy season and are at home in the tiniest mud puddle. The bangos, or milk fish (*Chanos chanos*), is extensively cultivated in ponds on the shores of Manila Bay. The most important group of fishes is probably the sardines, vast shoals of which are as yet almost unutilized, although canned fish amounting in value to several million pesos annually is imported. Groupers, mackerels, herrings, snappers, sea basses, porgies, pampanos, mullets, anchovies, barracudas, tunas, bonitos, and eels occur in such quantities as to be very important sources of food. The waters abound in sharks and rays, and the preparation of their fins for the Chinese trade is important and could be developed into a large industry.

Marine invertebrates.—Trepang abounds everywhere in the Archipelago, and large quantities are exported to China. Terrestrial and marine mollusks are exceedingly abundant, the Phil-

ippines having the richest molluscan fauna of any equal area in the world. Many are edible and are of great local importance. Pearl oysters are abundant, and the pearls of the Sulu Archipelago are world famous. The shells of *Placuna placenta* Linn. are so thin that they merely need to be trimmed to the proper size to be used instead of window glass; the latter is rarely seen in Philippine houses. The top shell (*Trochus niloticus*), the turban shell (*Turbo marmoratus*), and the pearl shells are extensively used for making buttons. The chambered nautilus is common, the paper nautilus less so. The land mollusks have been well studied; they are remarkable for their variety, beauty, and abundance.

Sponges abound in the southern islands, and the best grades are equal to those of the Mediterranean. Black coral, which looks like insulated electric wire, is much used for making bracelets and other jewelry. The coral reefs throughout the Visayan and southern islands form marine gardens of unsurpassed beauty. Arthropods are very abundant but little known. Shrimps, crabs, and marine crayfishes form an important source of food supply.

Insects.—Mosquitoes are numerous in the mountains as well as in the lowlands. There are beautiful butterflies, among which the birdwings easily take first place. *Ornithoptera trojana* Staud., found only in Palawan and closely related to *O. brookeana* Wallace, is one of the rarest insects. Beetles form a considerable part of the insect fauna and show strong affinities with those of Borneo and Celebes as well as with those of Java, Sumatra, and the Asian continent.

The silkworm has been introduced and thoroughly acclimatized, but there has been little effort to make it a commercial asset, although the capital required is insignificant in comparison with that needed in far less remunerative enterprises. Bees are abundant, and wild honey and wax are gathered in considerable quantities. The number of species of ants is very large. Some of them infest dwelling houses and swarm over the food. Some species of termites, or white ants, inflict great damage on wooden buildings. Plagues of locusts occasionally ruin growing crops; in damp wet weather these insects are supposed to be destroyed by a fungus growth (*Empusa*) within their bodies.

PHYSIOGRAPHY

DISCUSSION OF PHILIPPINE PHYSIOGRAPHY

Topography is the surface expression of geologic structure, while physiography is the interpretation of the origin of the topographic forms. Hence, in order to understand the topographic scheme or pattern of any terrane, one must know the underlying geologic structure and the geologic history of that terrane. For example, the topography of Bondoc Peninsula, Luzon, consists of various ridges and valleys, escarpments, gentle slopes, and accordant drainage systems. We find on close study of this region that in some cases the escarpments mark fault lines, the valleys sometimes follow approximately the crests of anticlines, and the synclines in many instances are the more-elevated areas, paradoxical as it may seem; the streams sometimes flow in certain very definite courses because of the structure of the underlying rocks, but owing to a previous start on a recent nearly horizontal wave-cut plain they occasionally take courses transverse to the trend of the sedimentary rocks. There are many exceptions to this rule in this region, and these are conditioned upon a possible former physiographic stage of development.

IMPORTANT GEOLOGIC AGENTS

The dominant geologic processes in the control of physiographic development are here recounted. The three most important geologic agents responsible for physiographic forms are diastrophism, gradation, and volcanism.

Diastrophism.—Diastrophism denotes the up-and-down movements in the outer shell of the earth. Such movements are negligible, apparently, in the older and more-stable portions of the earth, but even there they are occasionally manifested by earthquakes. In the newer parts, particularly along continental borders, they are of considerable magnitude and importance. For example, in the Philippines, within the relatively short period of time since the Pliocene, there has been elevation of the northern Luzon block amounting to about 1,980 meters, and within the Pleistocene a noteworthy submergence in other

portions—Masbate Island, for instance. There have been many such oscillations in this region, of greater or lesser degree, within late geologic times.

Gradation.—Gradation is next in importance. This is the sum total of the wearing-down process, in many respects the dominant type of geologic work. Analysis of this process shows that the following agents are contributory: Weathering, transportation, corrosion, and corrasion. I would, however, make corrosion a subhead under weathering, as two factors are involved, a mechanical deformation and a chemical change, either of which may precede the other. Once weathering or, to use a term defining it in part only, "slacking" has taken place, transportation does its work, and then corrasion, or mechanical wear, becomes operative, but not until there is movement.

Of course, these factors are operative in all countries and under nearly all conditions, but gradation proceeds at a maximum rate in the Tropics. Two reasons are given for this; namely, torrential rainfall and temperature or, in a word, climate.

In the Philippines there is a mean annual precipitation of well over 2,540 millimeters (100 inches), with sometimes an exceptional rainfall, notably that of July 14 to July 15, 1911, which amounted to 1,168.1 millimeters (46 inches) in twenty-four hours, as recorded at the Baguio Observatory. This is the world's record for a single rainfall. The reported rainfall of 23,387 millimeters (905 inches) in a year at Cherraponji, in Assam, has lately been questioned. However, a precipitation of over 15,240 millimeters (600 inches) has been recorded on Mount Waialeale, Kauai Island, Hawaii.

As the result of such heavy rainfall the streams leave their banks and spread over the country in sheets of water. An almost unbelievable amount of material is then transported. Velocity is an important factor to be considered. Doubling the velocity of a stream increases its transporting power sixty-four times.

Once the tropical downpour of warm rain has stripped off the soil, weathering can and does strike deeper into the core of the rocks beneath, and at any depth in underground mine workings, the rocks exhibit incipient decomposition. I know this to be true from examination of a great many thin sections of wall rock from the deepest mines in the Archipelago.

Undoubtedly, the presence of organic acids resulting from the decay of the rank tropical vegetation hastens decomposition. Of course, there is little or no frost, except in the highest mountains, but there are wide ranges in temperature in the highlands during the twenty-four hours, a factor which adds to the disintegrating forces at work. Therefore, all things considered, we have reason to think that gradation, which includes degradation, is the most potent of the geologic processes at work in the Tropics.

The excessive weathering in tropical regions, where andesitic and basaltic lavas are to be found, has resulted in places in the accumulation of thick beds of laterite. Vast deposits are known in India and in Cuba. In the latter country it is mined as iron ore. Laterite is an aluminous soil, or heavy clay, also rich in iron. When the iron exceeds 35 per cent it can be used as an ore. Some years ago an American engineer discovered a commercial deposit of this material in northeastern Mindanao; in that locality it is a product of weathering and concentration.

Volcanism.—Volcanism plays an important part in the determination of the type of physiography found in certain regions. Regions subject to volcanic activity of one kind or another have a topography which can be quickly identified and differentiated from that of a region not so characterized. Furthermore, an older topography due to a totally different kind of geologic structure may be either greatly modified or even completely obliterated by subsequent volcanic activity. A fine example of volcanic topography is that seen in the region of Mounts Isarog, Mayon, and Bulusan, where there is a fine cluster of cone-shaped peaks in various stages of denudation. Furthermore, the particular type of volcanism plays an important part in producing topographic forms. For instance, volcanism of the explosive type will yield sharp cone-shaped mountains, while volcanism manifested by the outpouring of lava will yield either low, dome-shaped mountains, or merely plateaulike features, as in the Pacific Northwest, in the United States. Something approaching this physiography can be seen in the Lanao region of Mindanao. We may, then, consider volcanism as a superficial agent in geologic processes.

Another important consideration is that volcanism is generally manifested most considerably along continental borders and is usually found to have a fundamental relation to the

tectonics of the region. This phase of the subject is discussed at greater length in the chapter on Volcanology.

SALIENT FEATURES OF PHILIPPINE TOPOGRAPHY

The salient features in the topography of the Philippine Archipelago are the following: The irregular configuration of the Archipelago; the great mileage of the coastline; the large development of mountains and the arcuate arrangement of many of them; the proximity of the mountains to the sea; the narrow and interrupted coastal plains; the principal intermontane plains; the river systems which principally flow north; and the great variety of lakes of diverse origin.

Irregular configuration of the Archipelago.—The general outline of the Philippine Archipelago is suggestive of a giant sloth sitting on its haunches, with Luzon for the head and shoulders, the Visayan Islands constituting the vertebræ and ribs, Mindanao for the pelvis, Palawan and Cuyo for the forelegs, and the Sulu group serving as the hind legs. The body of the animal appears as if it were slightly inclined forward. This analogy must not be carried too far, since the resemblance vanishes when we begin to look for the details of the skeleton.

The bulk of the land mass lies east of the main portion of Luzon, with its axis northwest and southeast. Extending southwestward and at about right angles to this line are the two long arms of the Palawan-Cuyo-Mindoro group and the Sulu chain of islands more or less parallel but separated by a considerable stretch of sea.

Irregular coast line.—A glance at a map of the Philippine Islands will impress one with the most important physiographic feature of the whole Archipelago; namely, the enormous extent of coast line—18,533 kilometers. This is due in part to the drowning of the dissected and faulted land mass. There are many small islands, and the larger islands are liberally supplied with indentations of varying size, which increase the length of coast line proportionately.

The present configuration of the land masses of the Archipelago, and hence the outline of the coasts, is due to complex movements along the main lines of folding and faulting. For instance, if we examine the hydrographic chart (Plate 37), it can be seen that there is a definite line, perhaps a fault line, running along the 500-meter line on the west side of Palawan which, if continued, would pass through the Taal Volcano re-

gion, where during the great eruption of 1911 fissures opened whose trends were about northeast and southwest. If this line were prolonged through Luzon it would pass close to the east coast north of Baler.

Again, the west coast of Panay, according to Mr. Palmer Beckwith who has studied that region, seems to be determined by a fault line, which if prolonged to the northward passes on the east side of Tablas. Many other illustrations might be cited in this connection.

*Development and arrangement of mountains.**—The mountains of the Philippines lie generally in ranges parallel and in close proximity to the coast lines. They are of two principal types; namely, those due to uplift, folding, faulting, and subsequent erosion, and those due to volcanism.

The most prominent chain, the Cordillera Central, † is in Luzon; it stretches from the northern boundary of the central plain to the Pacific Ocean, forming the backbone of the island. It is a composite of two, and in some places of three, parallel ranges, each of which averages about 1,800 meters in elevation.

The Cordillera Central, as well as the two coast ranges of Luzon, may be said to be in that stage of physiographic development known as "topographic youth" or, in places, "early maturity." Hence, the cross section of the stream valleys is V-shaped or may be modified to a broad U-shape by excessive talus accumulation from volcanic agglomerate cliffs above. Ledges and falls are common along the main channels, and there is rarely great accumulation of wash in the stream channels, owing to the terrific scouring of the mountain floods.

This cordillera consists of sediments folded, faulted, and eroded, exposing granitic batholiths, the whole yielding a maze of rugged peaks and formidable cañons. Later intrusions have further complicated the whole scheme.

Along the east coast of Luzon is a range of mountains of which practically nothing is known in detail, since it is very sparsely inhabited, chiefly by Negritos. In places this range attains an elevation of 1,800 meters, but in the main it is much lower

* The highest peak in the Islands is Mount Apo, in Mindanao; it is of volcanic origin and is 2,929 meters in height.

† The highest peaks of this range, beginning from the south, are the following: Mount Santo Tomas, 2,258 meters; Mount Pulog, 2,924 meters, the highest peak on Luzon; Mount Data, 2,670 meters; and Mount Amuyao, 2,702 meters. The range is largely composed of intrusive and extrusive andesite, with sediments exposed high on its flanks.

than the Cordillera Central. It is also known to be largely volcanic in origin, having an active vent, Mount Cagua, near its northern extremity.

Just northeast of the central plain these two ranges coalesce, forming what Adams(21) has called the "Central Knot." This constitutes the highland country of Nueva Vizcaya.

On the west, in northern Luzon, is located the Coast Range, known locally as the Malaya Range, which is narrow, and in places is 1,800 meters or more in altitude. This is also andesitic, with some sediments at high elevations.

In southwestern Luzon there is the Zambales Range, which consists of a line of more or less isolated, old volcanic stocks in various degrees of degradation. The highest points in this line are Mount Pinatubo, 1,781 meters, and the magnificent cluster of peaks known as Mount Mariveles, 1,420 meters, at the entrance to Manila Bay.

In southeastern Luzon there is the altogether different type of mountain, a cluster of more or less dormant volcanoes, of which the commanding figure is Mount Mayon, an almost perfect cone 2,421 meters in height, near Legaspi.

In the Visayan Islands, as a rule, a cordillera forms the backbone of each island. In the main cordillera of Panay there are peaks 2,049 meters in elevation, while in Cebu 1,013 meters is the limit. The Negros cordillera is not so well defined, but the island has one peak 2,438 meters in elevation—the dominant volcano of Canlaon. Little is known about the mountains of Leyte and Samar beyond the fact that there are some moderately high peaks of volcanic origin, none of them recent, however. In Samar there is no peak higher than 1,000 meters, and there is no cordillera.

The dominant cordillera in Mindanao is the Diuata Range along the eastern side of the island in Surigao Province. This consists of plutonic as well as extrusive rocks. There is also an interrupted volcanic chain, extending north and south in the central portion, in which is Mount Matutum. A cluster of volcanic peaks is irregularly arranged around Lake Lanao, and south of this lake is the east and west line of dormant craters of the Buldun Range. The Malindang stock in northwestern Mindanao is 2,425 meters in elevation, but is narrow. From the Malindang stock a low cordillera extends into Zamboanga Peninsula.

While many of the higher mountains are either worn-down volcanic stocks or more or less undissected and isolated cones,

yet there are many examples of the faulted and tilted block type, such as Mount Santo Tomas in Luzon.

As a rule, Philippine mountains are covered with dense forest, except in northern Luzon where a species of pine is the principal tree or where the people have burned off a great deal of the primeval forest, which has been replaced with a dense covering of the ubiquitous cogon and other coarse grasses. In some places, particularly well exemplified in the Zambales Mountains of western Luzon, there are forests near the foot of the ranges, and then between 900 and 1,650 meters the slopes are absolutely bare and rocky. Above this point the well-defined mossy forest covers the slopes to the summits.

The principal mountain passes and trails through the cordilleras are the following:

Bued River Gorge, Luzon (north and south), from the central plain to the Baguio Plateau.

Naguilian Road (ridge), Luzon, from the west coast to the Baguio Plateau.

Tila Pass, through the Malaya Range into Lepanto Subprovince, Luzon.

Balbalasang Trail into the Kalinga highlands, northern Luzon.

Villaverde Trail from San Nicolas, Pangasinan, to Dupax, Nueva Vizcaya.

Trail to Palanan Bay, northeastern Luzon.

Infanta–Tanay Trail across the rugged mountains east of Manila.

Bayombong–Echague Trail through Nueva Vizcaya to Isabela Province. A macadam highway is being constructed along this route, and an extension of the Manila Railroad along the route is projected. This will connect Manila by rail with the rich tobacco provinces.

Atimonan Road, southeastern Luzon; practically the only road to the east coast.

Cabanatuan–Dingalan Bay Trail. This pass, which does not go above 250 meters, separates two important massifs of the eastern cordillera.

Wright–Taft Trail, in Samar; practically the only route across this island.

Pikit–Digos Trail, in Mindanao; the most direct route from Cotabato to Davao.

Cebu–Toledo Road, Cebu Island; one of the most beautiful mountain roads in the Archipelago.

Pikit–Banisilan–Lanao Trail, Mindanao; this trail leads into the heart of Mindanao.

In addition to these, there are many shorter but important routes leading through the mountains of the smaller islands. The lowland people make frequent use of these natural lines of communication, but the hill people seem to pay little attention to

topography and often choose the shortest route even though it leads directly over the highest points. Neither the hill people nor the lowland people take much pains to follow contours in laying out their trails.

The highland plateaus.—In the central part of northern Luzon around Baguio, Pauai (Haight's place) and, again, farther north on Mount Data (Plate 19, fig. 2) near Mankayan, there are remnants of older and more extensive plateaus which may represent all that is left of former peneplanation and base leveling. Eveland(237) called attention to these areas and the great difference in topography exhibited by them and the surrounding regions where sharp cañons were dominant.

I have been of the opinion that these were purely local and could be accounted for largely by fill, due to torrential wash, in these higher regions. In a paper on the relation of tropical geology to engineering I emphasized this effect of torrential wash and the enormous work of floods during typhoons, particularly in the Luzon highlands. This must not be lost sight of in a study of the rate of erosion and deposition in this region. In a deforested region, like much of northern Luzon, the results are still more apparent and the action enormously speeded up. Recent work by Dickerson, with whom I had the privilege of revisiting much of this ground, seems to indicate that these remnant areas of mature and even old-age topography confirm Eveland's opinion that they represent peneplanation. Dickerson places this base leveling in the late Pliocene or early Pleistocene period which, according to him, extensive faulting has isolated and preserved for us in blocks like the Baguio Plateau. The critical feature in this region (and it throws illumination upon the whole study) is the course of Trinidad River, which is discussed by Dickerson.* This stream is clearly antecedent, as indicated by its cutting across the structure of very diverse formations (fig. 2). Eveland made no statement as to the age of the stream, nor did he emphasize the part played by faulting.

The finding of fossils of very recent-looking, lowland plant leaves in the Pleistocene (or Pliocene) tuff at about 1,950 meters elevation on the Sagada Plateau remnant still farther north in the Mountain Province, where both the tuff beds and the Malumbang limestone beds are truncated, gives us a means of placing these events in the geologic time scale.

* The development of Baguio Plateau: A study in historical geology and physiography in the Tropics. Philip. Journ. Sci. 23 (1923) 413–453.

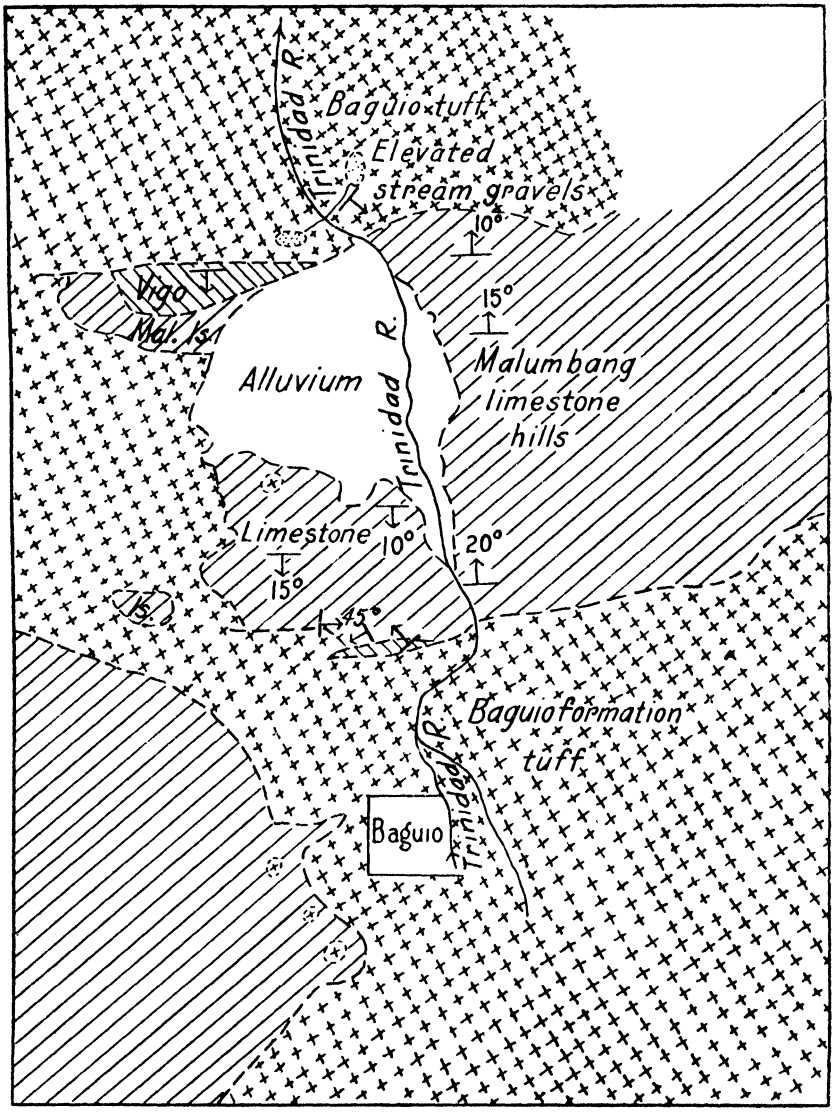


FIG. 2. Sketch map, showing the geology along Trinidad River in the vicinity of Baguio.

As far as I know, there is no counterpart of this high-level plateau anywhere in the Archipelago, unless it be the fairly elevated plateau of Bukidnon,* Mindanao, which is much lower.

* C. F. Baker, dean of the College of Agriculture, University of the Philippines, who has traveled through Bukidnon, informs me that this plateau is largely filled with wash from the surrounding higher mountains; photographs of that region confirm this statement.

I have not seen the latter. The plateau of Lake Lanao in central Mindanao is of volcanic origin entirely, though there might be an old erosion surface beneath the Pleistocene lava flows of that region.

The intermediate uplands.—Between the cordilleras and the plains, along the flanks of the higher ranges, there is an intermediate zone of upland country of generally mature topography, consisting principally of foothills. The slopes are more or less rounded and grass covered. The dominant rocks are Tertiary sediments, and there are extrusive bodies of andesite and related rocks. A typical example of this topography is found in western Masbate where the monoclinal sediments, shale, sandstone, and limestone, have yielded a characteristic topography quite different from that in the central part of the island, which is rugged cordillera.

Proximity of mountains to sea and coastal plains.—As a consequence of the proximity of the mountains to the coasts, we would expect to find, and do find, that there is little or no development of coastal plain, and that, where it does exist, the coastal plain is comparatively narrow. However, with the steady growth of the coral platforms about much of the coast and the contemporaneous deposition of great volumes of débris from the mountains, coastal plains are rapidly growing. Of course, coral growth and wash from the land are not sufficient; elevation is a necessary factor in the formation of coastal plains of much size.

One outstanding factor that accounts for the lack of coastal plains, as pointed out by Semple, is the deep surrounding seas; that is, in much of the Archipelago there is little or no shallow continental shelf on which alluvial material could accumulate. Faulting and rapid elevation may be the reasons for this.

A coastal plain more than 16 kilometers wide is an exception in the Philippines. Attention will be invited to this topic again, in connection with the physiographic influence upon human activities.

Aggradational plains.—A type of plain more important than the coastal is exhibited by the plains found lying between the mountains, though not strictly intermontane, and on these plains the greatest development of civilization in the Islands is to be found. The principal ones are the following: The central plain of Luzon; the Bicol plain of southeastern Luzon; the Cagayan basin of northern Luzon; the central plain of Panay; Agusan

Valley, in eastern Mindanao; and Cotabato Valley, in southwestern Mindanao.

As a rule, these plains have been formed by the aggradation of depressions, by means of coalescing alluvial fans, between two isolated land masses which were separated in Tertiary time and probably also in Pleistocene time. They generally are much wider than the coastal plains, though they have much the same origin and composition. In individual cases other factors have complicated the history. As these are fully described and their origins discussed in the several regional sections, this subject will be dismissed here. With the exception of the Cagayan, the plains are broad and flat, holding the largest population of all equivalent areas. Cebu Island is an exception in the latter respect, the people there living mostly on the coastal plain, there being no central plain and the interior having a high and rugged character.

River systems.—As pointed out in the beginning of this book, there are a few large rivers in the Archipelago, but in the main the streams are short and swift. This is a natural consequence of the small land masses and the youthful topography. A noteworthy feature of the rivers of the Archipelago as a whole is the predominance of north-flowing rivers among the larger ones. In the order of their present importance, the principal rivers are the following: Pasig, west flowing; Pampanga, south flowing; Mindanao, southwest flowing; Cagayan, north flowing; Agusan, north flowing; Bicol, north flowing; Abra, north flowing; and Agno, southwest flowing.

The courses of these streams are controlled mainly by tectonic lines, folding, and faulting, but portions of their courses can be explained only on the basis of previous physiographic history of the particular regions through which they flow, by accidents of deposition of load, etc. These and other important rivers are considered in the regional sections.

Lakes.—There are several types of lakes in the Philippines. It is difficult to say which type is dominant, but those due to some sort of damming of a preëxisting drainage basin, generally by lava or ash deposits, seem to be in the majority. The types are lava-dam lakes, explosion crater lakes, land-subsidence lakes, oxbow lakes, dune lakes, and synclinical (?) lakes.

It is very probable that many of these lakes have originated through the operation of more than one of the causes enumerated, as in the case of Laguna de Bay, which may have been formed

through subsidence in part and also by a barrier of arched tuff beds being elevated between this low strip and the sea.

Of the first type we have Lake Lanao in Mindanao and Lake Mañguao in Palawan as examples.

Explosion craters are well exemplified by the new lake in Taal Volcano crater formed in 1911. Probably Bombon, the large lake surrounding Taal Volcano, is due to subsidence.

For the fourth type we may follow Agno and Pampanga Rivers in the central plain of Luzon for numerous unnamed examples. These are merely cut-off, oxbow bends in the meanders of those streams.

The best example of the dune type is Lake Paoay in Ilocos Norte.

The sixth type in our list is doubtful; Lakes Malanao and Balut near Cotabato seem to me to be synclinal, but I did not examine them closely.

Pratt,(500) in his paper on Philippine lakes, summarizes much of the scattered literature on the subject.

VOLCANOES

Slight mention has been made of the volcanoes of the Philippines, their general locations being given. Topographically these are the most conspicuous features in the Philippine landscape. We find every gradation, from the almost perfect cone of Mayon in Albay Province, which is perhaps the most symmetrical mountain in the world, to old worn-down volcanic stocks, now completely dissected, whose form gives scarcely a suggestion of their origin.

Most recent volcanoes are composed of pyroclastic materials and their slope angles are the angle of repose for these materials; consequently, they contrast greatly with those lava-flow volcanoes of Hawaii whose slopes are very gentle.

As these topographic features are conspicuous, many persons get the erroneous idea that the dominant formation in the Philippines is volcanic, whereas there are great areas where the surface rocks are either plutonic rocks or sediments, both having a quite different type of physiography. Volcanoes form the subject of a special chapter.

CORAL REEFS

Coral reefs are especially important in the Philippines, not only because of the part that corals play in the making of land and in the production of special land forms, but also because

of the light that their study in this particular region throws upon the great questions raised years ago by Darwin.

As I have made only superficial studies of corals and coral reefs in the course of my economic work, I shall merely quote some important paragraphs from a recent discussion by W. M. Davis and comment on some of the points raised by that author. His main thesis is stated in the following paragraphs:

Unconformable fringing reefs of a new generation appear to characterize the shores of the Philippine Islands to a remarkable degree, while barrier reefs and atolls are rare thereabouts, as may be learned from the admirable charts recently issued by our Coast and Geodetic Survey; and yet no one has, so far as I have read, perceived that the facts thus presented afford strong testimony for Darwin's theory of subsidence. The manifestly unconformable contacts of the fringing reefs on the maturely dissected and more or less embayed shores of many members of the much disturbed Philippine group, largely formed of non-volcanic rocks, demand long continued erosion while the islands stood higher—in several cases much higher—than now, and a correspondingly great, though by no means uniform or universal, subsidence to bring them down to their present position; and this at so rapid a rate that preexistent reefs, if they existed, were drowned, and at so recent a time that the fringing reefs on the headlands and the deltas in the bay heads have not as a rule attained great development. The west coast of Palawan, the southwesternmost member of the Philippines, gives many striking illustrations of these features, none more impressive than at Malampaya Sound, here shown in figure 10, reduced from a part of Coast Survey chart 4316. Joubin's chart of coral reefs (1912) gives the fringes of the Philippines a much greater breadth than they usally possess.

The existence of earlier formed reefs at lower levels, now drowned, is highly probable on many of the Philippine Islands, for the absence of strong cliffs on the headlands of their embayed shores indicates the presence of protecting reefs while the coasts were suffering erosion before their recent subsidence; thus all the more does the absence of an extensive system of offshore barrier reefs, which should have grown up from the preexistent reefs during a slow subsidence, indicate that subsidence was more rapid than reef upgrowth. Moreover, the submarine platforms that border some of the islands are best explained as submerged and more or less aggraded reef plains, on the outer margin of which new barrier reefs have failed to reach the present surface because of rapid and recent subsidence; indeed, some of the platforms have no sign of upgrowing marginal reefs, and these must have been submerged with unusual rapidity at a very recent date. It is quite possible that some of the shorelines here treated as showing recent submergence may have afterwards emerged by a moderate amount from a previous greater submergence of moderate duration, for charts do not always suffice to distinguish between these two cases; but in either case, the fringing reefs would rest unconformably on their foundations.

The facts here discovered seem to me to give strong confirmation to Darwin's views; not only so, they show that, after the many other move-

ments the Philippines have suffered, the recent subsidence of many of the islands has been more rapid than reef upgrowth, and hence more rapid than the subsidence of most of the islands in the central Pacific around which barrier reefs or above which atolls are commonly found. In this respect I believe the recent history of the Philippines to be representative of that of the other archipelagoes of the western Pacific, where, in spite of the evidence for submergence given by strongly embayed shorelines, barrier reefs are imperfectly developed and atolls are rare.

The so-called atoll noted by Semper in Benguet and referred to by Davis, is clearly not an atoll and is the result of erosion.

The unconformity between the "lignitic series and the coral mantle," also referred to by Davis, is one of the greatest in the Philippines and is widespread. It lies, to give a more accurate description, between the Malumbang (Pliocene) and the Vigo (Miocene).

Davis's point about the complexity of events in the geologic history leading to the present physiography of the Archipelago is well taken. A review of my earlier work as well as of the literature led me, after revisiting many of the localities, to concur with Davis (who, by the way, has never been on the ground) in the belief that the story is far more complicated than either he or Becker had supposed.

Masbate furnishes, as pointed out by Ferguson some years ago, indisputable evidence of marked recent subsidence, and the hydrographic charts show, on the north and west at least, no submarine platform, but deep water; all of which certainly confirms Davis's view.

I concur with Davis in believing that the Philippines furnish no evidence to support the highly speculative theory of glacial control, while Dickerson's comment is that the evidence is neither for nor against such control.

In discussing these points Dickerson expressed the opinion that, while Davis's contention undoubtedly holds true for Palawan, it does not apply to the Philippines as a whole, and that rapid uplift is the dominant cause for the lack of development of fringing reefs of the present generation in many of the islands studied by him. I am inclined to concur with Dickerson in this view, since in spite of a few instances of local and, in places, considerable subsidence the last great event has been a tremendous and rapid elevation of most of the Archipelago.

In additional paragraphs, which are not quoted here, Davis discusses the history of the Philippines, as enlightened by a study of coral growth, and then passes to the bearing of the facts, as

gleaned from those studies, upon the glacial-control theory. I shall not attempt a discussion of these points.

The raised reefs on many stretches of Philippine coasts, particularly well developed on Bondoc Peninsula, are a conspicuous topographic feature with their fairly level platforms due to the limiting of the growth of the coral by the sea surface. In many parts of the Islands in the lowland regions (Bondoc Peninsula, Luzon, for example) are extensive areas of more or less uniform surface which may be in part wave-cut, in part base-leveled, or due to lava flows, but many of these may be and are found to be due to the presence of reef limestones.

Near Fort Pikit, in Cotabato Valley, Mindanao, there are several fairly even-topped, moderately high hills, say 60 meters, which form conspicuous features of the landscape. These are found to be composed of reef corals in great quantity, entire hills being made up wholly of reef limestones. From a study of the corals and their state of preservation, it is clear that they are Pleistocene. Similar elevated reefs are found in central Panay. Attention has been called to the comparatively recent corals in the limestones in the Mountain Province, Luzon, at an elevation of over 1,500 meters, and their bearing upon geologic and physiographic history.

LANDSLIPS

In consequence of the nature of the formations, heavy rainfall, and seismic disturbances, nearly all parts of the Archipelago are subject to landslips of greater or lesser magnitude. This is particularly true of the highlands of Luzon, where in many localities the formations are, to a considerable extent, limestone covered with volcanic flows and loose ejecta.

At Baguio a slide occurred in 1914, which by actual measurement showed a slip of 25.4 millimeters an hour. This and other great slides are described in the section on Luzon.

A landslide from one side of Bued River Cañon during a heavy rain caused the formation in the gorge below of a dam of loose material to a height of 18 meters. When the impounded water broke through this dam, everything in the cañon below for several kilometers was obliterated, and steel girders or bridges were carried far out onto the central plain below. In the Mountain Province of Luzon we have an excellent geological laboratory where we can see "geology in the making."

The present land forms in the Philippines have come about through a complicated set of processes, elevation, subsidence, folding, faulting, volcanism, and gradation. There have been repeated elevations and subsidences, with longer and shorter pauses, during which approaches to peneplain conditions have been attained. Because the story is complicated and we have worked only a few areas in detail we are not in position to outline the physiographic story clearly.

From very early times doubtless there have been archipelagic conditions in this part of the world, though the island masses may have been much smaller. This is known positively in the case of Luzon and Mindanao, but in the Visayas the land masses may have been larger. Extensive faulting was the cause of these changes.

As soon as the original land areas emerged from the sea they were eroded and deposits were formed. These were subsequently elevated, folded and faulted, and eroded again—how many times we do not know. Of pre-Tertiary conditions and events we have little from which to make deductions, as the remains of rocks dating from those periods are few and scattered. Perhaps in some areas old erosion surfaces dating from this time will be found preserved, but the probability is very great that they are concealed by later formations or modified by subsequent events.

During the Eocene much of the Philippine terrane was above water. We have found no undoubted Eocene marine deposits and no terrestrial deposits that can be identified as such.

Following the deposition of the Batan coal measures and the Vigo shales there was a period of pronounced folding with faulting, elevation, and subsequent erosion. During this time there was also considerable extrusion of lava and agglomerate. Remnants of this older land are found in many parts of the Archipelago.

Subsequently occurred submergence and the deposition of vast amounts of limestone, tuffaceous materials, etc., and again elevation, followed by erosion. Since the late Pliocene there has been chiefly elevation in Luzon and Mindanao, while in parts of the Visayas and Palawan submergence has been the rule.

Concomitantly with the elevation there has been extensive coalescing of the isolated land masses by gradation and volcanism, particularly in Luzon and Mindanao. Prior to this time the Zambales mountains were separated from the eastern cordillera by a stretch of sea from Manila Bay to Lingayen Gulf.

Likewise, Mindanao consisted then of several isolated land areas. The Cotabato region was generally covered by an arm of the sea. The physiographic changes in the Philippines have been rapid, and apparently they are continuing undiminished to-day.

As a result of all these events there have been many interesting drainage changes, some of which will be discussed in the regional chapters. Furthermore, since the several islands in many instances have had different geologic histories, it seems now impossible, or at least undesirable, to attempt a statement of the physiographic history of the Archipelago as a whole. Therefore, such statements as can be made on this subject will be found under the regional headings.

HUMAN RESPONSE TO PHYSIOGRAPHIC CONDITIONS

Some of the more-prominent illustrations of geographic and physiographic influences on humanity in the case of the Philippines are discussed in this section.

The principal and most-advanced population is found on the great central plain of Luzon. At the lower end of this plain, where Pasig River enters Manila Bay, is located Manila, the largest city of the Archipelago. The location of the metropolis is controlled absolutely by the juxtaposition of sea, plain, lake, and river—a combination such as is found nowhere else in the Archipelago. The Tagalogs happened to be living at this place when the Spaniards came.

The Ilocanos of northwestern Luzon, who impress one as being very energetic and thrifty, afford an especially fine illustration of the influence of geographic position. They live on the narrow coastal plain in the part of Luzon nearest to China. Historical records show that the Chinese trader and sea rover touched at Ilocano points first. The basic agricultural practice in the Islands to-day is of Chinese origin.

The present condition of civilization of the peoples of north-central Luzon is to be attributed primarily to the nature of the country that they inhabit, this having served to keep them in isolated groups. The political and cultural unit in this region is the village, and the size of the village is dependent on the amount of irrigable land in any locality. The generally inimical feeling that existed until recently between the inhabitants of the different towns was due almost solely to lack of contact, and this is

to be attributed to the absence of easy communication. In fact, almost all of the differences in the Archipelago to-day, as in many other parts of the world, are due to isolation. It is noteworthy that a prominent and highly educated ex-official in the Islands, himself a low-country Filipino, said that the first Igorot he saw was at the Saint Louis Exposition.

The Igorots furnish an excellent example of the influence of topography on a people. The basic factors in the life of a people, from the Occidental standpoint at least, are economic. It is well known that the Igorots have put into operation a notable system of irrigation. Its origin is not attributed to the Igorot himself, for it seems probable that this came from the mainland of Asia; but he does use it, and that remarkably effectively. While in some parts of the low country the Filipino is nearly starving for want of rice, his highland brother sometimes raises three rice crops a year on ground very difficult to prepare for a crop of any kind.

Some of the physiographic and geologic factors that have produced the kind of civilization found in north-central Luzon are altitude, rugged topography, extremely accentuated relief, absence of navigable streams, and distance from the sea.

Altitude has given the highlander the energy that sets him apart at once from the low-country plain dweller. Rugged topography has prevented the formation of large natural groups and has accentuated the family and village life. Absence of navigable streams and distance from the sea, the oldest and greatest natural highways, have kept the people from traveling far from home.

That the system of irrigation and the raising of crops on terraces on steep hillsides is directly referable to the natural topography is clear. Not only must these people work very hard, but they must work practically all the time to gain a bare subsistence (there being little game in the country), which is another important reason why the various communities do not mingle more than they do. Therefore, the policy of the Government of affording communication by means of trails and roads is of paramount importance in bringing together the isolated groups.

In passing through the country lying east of Bontoc and south of Cagayan Valley, the "No Man's Land" referred to by Worcester, I was struck by the generally impoverished condition of the people there. They live in extremely small and scattered com-

munities, in squalid surroundings, with both mongrel customs and mongrel dialect—the so-called "Gaddang." If the character of the country is noted, the cause is apparent. The underlying formation, sandstone, is not such as to yield the most fertile soil, even though it is a soil made up of triturated fragments of volcanic formations. In the second place, the country is characterized by swales and hummocky hills, with little forest. This section is not inaccessible and consequently there is some mingling with the lowlanders, though that does not appear to have wrought any improvement in the inhabitants. This apparent contradiction to foregoing remarks may be explained by the fact that the means of intercommunication are just difficult enough to bar any except the most adventurous and unscrupulous from going backward and forward, and so the hill man often is exploited without being materially benefited by contact with outsiders. This region well may be the rendezvous of the inferior and vicious elements driven out of the surrounding sections.

Cebu Island and its people furnish another fine example of physiographic influence. Here is to be found the most-congested population in the Archipelago. It practically is confined to a narrow and interrupted coastal plain, which has only a rugged mountainous interior and little productive hinterland. The reason for the excessive population of Cebu in proportion to its area of arable land is not known. Perhaps the Visayan is more fecund than are the other groups. The density of population of Malay islands may be partially explained, as Semple* says, by "the attraction of the coast for the seafaring Malay race" and "the mathematical law of increase of shoreline with decrease of insular area."

Panay offers another instance of physiographic control. The Negritos, a backward and vanishing tribe, are located in the most inaccessible parts of the cordillera. A second group, known as the Montescos, live in the rugged and unproductive intermediate uplands, while the more progressive Visayans inhabit the plains. Even among the last named there is a difference in dialect between the Visayans living on the Iloilo plain and those living north of the upland barrier, an east and west, 100-meter ridge which connects the cordillera with the low mountains in the eastern part of the island.†

* Influence of Geographical Environment, p. 452.

† Beyer recognizes four subdivisions; namely, Cebu Bisayas [Visayans], Samar-Leyte Bisayas, Panay Bisayas, and Aklan Bisayas—the last named in Capiz Province.

In the Philippines there seems to be found at least a partial confirmation of the dictum laid down some years ago by a student of history, to the effect that land masses, more often than oceans, have been barriers to migration. Very often people living on opposite sides of a stretch of sea are found to be more nearly alike than are people living in different parts of the same island or land body. There is more homogeneity among the peoples of the Visayan Islands than among those living on Luzon. This is what would be expected, however, in the Malay region, where the people live largely on and by the sea.

The location of highways in the Philippine Islands probably is the best instance of the influence of topography on the affairs of men, a notable example being furnished by the famous Benguet Road. Here was a project which seemed feasible and satisfactory from every point of view, but the factors of topography, precipitation, and the character and structure of the rocks controlled absolutely. The nature of the rocks—badly weathered andesite—in the cañon walls alone was enough to condemn the undertaking. As originally laid out the road was a failure, and we now know that in the Tropics to locate highways in beautiful cañons is perilous. The change of location of this one road will affect the whole countryside, the growth of cities, as well as many minor enterprises. For Philippine highways of the future, in highland country at least, ridges must be resorted to, for these are safe, while in cañons the overhanging cliffs and the powerful undercutting streams are unsafe.

LOCATION AND GROWTH OF CITIES

Manila, Luzon.—The location of Manila is unique; from geographic, physiographic, and commercial standpoints it is one of the best-situated cities in the Archipelago, perhaps also in the world. In its immediate surroundings the following points of paramount importance are to be noted: It is located about halfway between the northern and southern ends of Luzon, almost at the geographic center; it is at the head of one of the finest bays in the world; it is at the lower end of the largest plain of the Archipelago; it is at the mouth of Pasig River, the main artery leading to the rich Laguna de Bay country; the narrow opening and wide flaring of the bay on the inside preclude any possibility of serious damage from seismic waves. Although the harbor was not made absolutely typhoon-proof by nature, on account of the size of the bay and the low land almost surround-

ing it, it has been made nearly so by the construction of a breakwater at a short distance from the Manila shore. As the greatest single area of agricultural land and the largest easily accessible population are to be found on the central plain of Luzon, Manila is given a commanding trade position within the Archipelago.

When we consider Manila in its larger, world relationship, we see that it is the logical distributing point for a vast and richly productive region. This preëminence is due to its geographic position, about midway between the rich and populous Pekin plain and the valley of the Yangtze in China and Australia. Its situation with respect to the rest of Malaysia is very advantageous. The building of the Panama Canal has brought Manila into closer relationship with the United States than was formerly enjoyed, by establishing a more direct connection with the Atlantic States. Finally, its position, facing the greatest all-water route from the Pacific to the Atlantic, by way of the China Sea, Indian Ocean, Suez Canal, and Mediterranean, is of paramount importance.

Dagupan, Luzon.—Dagupan is located at the head of Lingayen Gulf, and was once an important entrepôt, but is no longer so. It is still important as a "mountain gate" city, standing at the upper end of the central plain. It is an important point on the Manila and Dagupan Railroad, and was for many years the northern terminal of this railroad; but this very railroad connection with Manila also has helped to destroy Dagupan's chance of becoming the leading port of the Archipelago.

San Fernando, La Union, Luzon.—San Fernando will soon be the terminus of the railroad (now at Bauang). The United States Army has constructed a pier in the naturally protected harbor, and the town is a port of entry to Baguio. San Fernando is situated on the rich Ilocano plain, along which there are excellent highways.

Cebu, Cebu.—Cebu, the second city of the Archipelago, is the main distributing point in the Visayas and enjoys good anchorage and shelter from storms. On account of coal and labor supply, it will become the chief manufacturing center of the Archipelago.

Iloilo, Panay.—Iloilo is the third city in size and ought to surpass Cebu, because it has a productive back country. It is growing very fast and has good shelter and anchorage. Both Iloilo and Cebu would suffer from waves produced by seaquakes and typhoons, owing to the funnellike nature of their harbors.

Zamboanga, Mindanao.—Zamboanga is a beautiful little town situated on a prominent trade route to Australia. It has little tributary country.

Cotabato, Mindanao.—Cotabato is slightly off the Australian trade route, but it has an immense and potentially rich hinterland. Some day this should be the metropolis of the southern islands. However, it has a serious disadvantage in the bar at the mouth of the river. The better harbor for the Cotobato Valley is Parang.

Aparri, Luzon.—Aparri owes its prominence to the great Cagayan tobacco country. Its poor harbor facilities and its distance from main steamship tracks always will militate against it.

Legaspi, Luzon.—Legaspi is a depot and entrepôt for the rich hemp district of southeastern Luzon. This city should increase in importance when the railroad from Manila reaches it, though it has an unprotected harbor.

Naga, Luzon.—Naga is located at the head of navigation for small ocean-going vessels on Bicol River. It also taps the Albay hemp region. It probably never will become of first importance, because none but shallow-draught boats can reach it.

EFFECTS OF MODERN IMPROVEMENTS

The railroad, the macadam road, and the telegraph are the powerful factors at work in breaking up the age-long isolation of the peoples of the Philippines. When we take into account the handicaps of rugged mountain barriers, tempestuous seas, typhoons, and plagues of all sorts with which the Filipino peoples have had to contend, we must give them much credit.

I venture to suggest that the future historian of these peoples study the topography and geology of the Archipelago and of the Far East, for then he need not be surprised at the rational manner in which events are related to each other.

STRATIGRAPHY AND CORRELATION

As has been pointed out by many investigators, the essential geologic unity of the Pacific basin is well established. I should like to point out an additional fact; namely, that if we were to flatten out the globe the western coastal margins of the Americas and of eastern Asia would be seen to fall into one line, and that fairly straight, so that really western America and eastern Asia are on the same side of the Pacific. Therefore, it would be only natural to find much agreement between the stratigraphic columns of eastern Asia and of western America.

CORRELATION

An approximation to the general stratigraphy of the Philippine Islands is given in Table 3. This table has recently been revised with the assistance of Roy E. Dickerson.

As Java is the nearest region in which detailed geologic and stratigraphic work has been done, I take from Verbeek and Fennema * the stratigraphic column shown in Table 4, which will reveal at once the close similarity between the two columns.

TABLE 4.—*Stratigraphy of Java, beginning with the oldest formation.*

1. Argillaceous schists, quartzites with quartz veins, without petrifactions (schists of the Carimuon dia)..... Age?
2. Schists with serpentine, mica, chlorite, and argillaceous material, quartzites, some calcareous beds and interposed sills of eruptive rocks, diabase, gabbro, quartz phorphyry..... Cretaceous.
3. Gray quartzose argillites with beds of coals, breccias of diabase, quartz, etc., conglomerates of quartz and granite, marls with alveolines and limestones with nummulites..... Lower Tertiary, Eocene.
4. Eruptive rocks in the preceding stage, the oldest andesites, with the characters of diorites and diabase..... Lower Tertiary, Eocene.
5. Terrane of Nanggoulan Oligocene.
6. Eruptive rocks at the base of the Miocene.
7. The lower stage of the upper Tertiary, called the "breccia stage," composed of breccia of eruptive Tertiary rocks with grits, shales, with some marl and beds of limestone..... Lower Miocene.
8. Eruptive rocks of the preceding stage..... Lower Miocene.
9. The middle stage of the upper Tertiary, called the "marly stage," containing much marl and marly sandstones, but less of sandstone and shales; some calcareous beds.

Middle Miocene with the uppermost beds in part Pliocene.

* Description Géologique de Java et Madoura. Amsterdam (1896).

10. Eruptive rocks of the preceding stage..... Middle and upper Miocene.
11. The most recent stage of the upper Tertiary called the "calcareous stage;" much limestone and marly limestones alternating with marl Upper Miocene and Pliocene.
12. Recent volcanic rocks; volcanoes.
Miocene, Pliocene, Quarternary, and Recent.
13. Old post-Tertiary sediments with some fossil mammals.. Quarternary.
14. Recent post-Tertiary sediments Recent.

If each of these items is examined in turn considerable similarity can be seen to the formations in the Philippines.

No. 1 can be duplicated almost exactly in various parts of Luzon (Caramoan Peninsula), Mindanao, etc. As in Java, the age of these metamorphics is uncertain.

No. 2 can be duplicated in several localities in the Philippines, particularly in Palawan. However, there is no evidence that Philippine rocks of this type are Cretaceous.

No. 3 can be duplicated in part on Batan Island southeast of Luzon, and in the Visayas generally.* I have found no undoubted nummulites in the Philippine coal measures but, on the other hand, I have found an abundance of Foraminifera of the genus *Lepidocyclina.*

In the Mountain Province, in Cebu, and in various other parts of the Philippines there are eruptive rocks of different ages, some old, some young. The older andesite in the Mountain Province can scarcely be distinguished from diorite and, in places, appears to grade imperceptibly into it. These may be similar to No. 4.

I have not yet been able to differentiate the igneous rocks of the Philippines as distinctly as Verbeek and Fennema have done in Java. Agglomerates, as I prefer to designate "volcanic breccias," occur undoubtedly at several horizons and it is quite probable that one of these corresponds to No. 7 in the Java table. The principal agglomerate in the Philippines is post-Vigo and pre-Malumbang.

Nos. 10 and 11 certainly can be duplicated at many points in the Philippines.

No. 12 certainly finds its counterpart in the Philippines.

No. 13 is represented in the Philippines by late Pliocene deposits in Agusan Valley, Mindanao, and in the great tuff deposits of the Manila plain. A few fossil teeth of mammals have been found in the latter formation.

No. 14 is, of course, widely represented in the Philippines.

* In this case lithology means but little, since the lignitic series in the Philippines appear to be Miocene, while in Java they are Eocene.

I know of no rocks certainly of Mesozoic or Paleozoic age in the Philippines, aside from the radiolarian cherts, which clearly are to be correlated with the cherts of Borneo and with the Franciscan of California and, hence, are to be considered Jurassic in age. Naturally, I am very much interested to learn that so-called "ancient" rocks are to be found in Formosa. Without fossils or undoubted stratigraphic evidence I am not willing to call schists and gneisses ancient just because similar rocks are found in the Archean. These are products of dynamic metamorphism, and not of time. It is quite possible, of course, that Formosa is geologically distinct from the Philippines, and more continental in this respect. It is known that the affinities between the lowland floras of Formosa and China are not repeated in the case of Formosa and the Philippines, although in the highlands the floras are strikingly related. It may very well be that Formosa is distinctly older. The Eocene has been recognized there, but the Paleozoic rocks reported from there are open to question.

In several islands, notably Luzon, Masbate, and Cebu, there are red and black argillites, almost slate in places, which may be Mesozoic or older. They probably are equivalent to the "Danau formation" (Molengraaff), or old slate, in Borneo. No fossils have been found in these rocks.

In as much as during the Tertiary (perhaps in the lower Miocene conforming with the same event in America, an event which was undoubtedly widespread) the European Tethys of Suess was closed, an attempt at correlation with Europe in the latter part of the column is unsafe. Table 5, facing page 68, based on Foraminifera studied some years ago by Douvillé, shows a tentative correlation with the European column.

It has long been known that in the tropical Pacific the rate of evolution has been very slow, so slow in fact as to cause me to make the statement several years ago that "in the Philippines we are still in the Tertiary period." The percentage of living forms, as shown by Martin, even in the older formations of the Tertiary, is greatly in excess of what we are accustomed to find in the same formation in temperate regions; therefore, the percentages usually employed in making the divisions in the Tertiary require modification. Recent detailed work by Dickerson on the Vigo fauna fully substantiates this.

In Table 5 an attempt has been made to correlate the principal formations and horizons in this Archipelago with those of the other Malay regions and of Japan. Such a table is likely to

contain errors, but it is at least suggestive and, therefore, may be of some benefit to future workers.

Some instances of special correlation with the American side of the Pacific may be cited, though these are not to be applied too strictly.

Coal.—In the countries about the Pacific there is coal of several geologic horizons, but in Japan, the Philippines, and Oregon most of it is Tertiary in age. The remarkable physical and chemical similarity between the Philippine and the Oregon coal is noteworthy.

Petroleum.—The petroleum of Japan, New Zealand, the Philippines, and California (with the exception of some Cretaceous) is of Tertiary age. According to Australian geologists, New Zealand is called the oil arc. As in the Philippines and Japan, the oil arc is the outer arc of folded Tertiary shales and sandstones. It is true that the petroleum of California and that of the Malay region differ greatly, the base of the former being generally of asphalt, and of the latter paraffin.

The metals.—In Korea, the Philippines, Oregon, and California, and perhaps in other countries bordering the Pacific, the most-productive ore deposits are associated with post-Jurassic granodiorite and quartz diorite intrusions. These are usually contact deposits or are in fissure veins not far from such contacts. Some less-important deposits in later (Miocene) Tertiary lavas are found about the Pacific arc.

Volcanism.—Attention has long been called to the volcanism about the Pacific, and the phrase "Circle of Fire" is the nickname given to the Pacific border by geologists. This is a happy designation not only of present conditions, but of conditions that obtained throughout the Tertiary. However, for outflows of lava comparable to those of the west coast of America in Tertiary times we must go to the great Deccan Plateau of India.

In the last volume of de Margerie's admirable French translation of Suess's great work,* is a map, compiled largely from Harker,† with which I am constrained to take issue. On this map are included the Sierra Nevada, Cascades, and Coast Ranges of western America in the "Andin (Andean?) Edifice;" and the continuation of the "Asiatic Edifice," according to this map, is to be found in the Rocky Mountain region of the United States. For such correlation there appear to be no supporting

* The Face of the Earth. † Natural History of Igneous Rocks.

facts whatever. Both Becker and I have found a remarkable similarity between the igneous rocks, structure, and geologic history of the west coast of America and those of the east coast of Asia.

STRATIGRAPHY

BASEMENT COMPLEX

Below the cover of sediments of the Tertiary, and perhaps also of the pre-Tertiary, there is a complex of igneous rocks, principally diorites, constituting the foundation upon which the Philippine superstructure rests. With the diorites are granite, pyroxenite, and diabase intrusions whose relations are not everywhere easy to see. The age of each of those plutonic and intrusive rocks is also a matter of conjecture. In neighboring countries such formations as these, with the gneisses and schists, which locally result from their metamorphism, have been placed in the Paleozoic and Archean. What the justification for this is I do not know; all that can safely be done is to place them in the pre-Tertiary.

On Zamboanga Peninsula I have found schists which grade into Tertiary sediments, sandstones, and shales. Pratt found similar conditions in Caramoan Peninsula.(497) In the Paracale district schists, which are merely metamorphosed diorite and gneisses that are simply badly squeezed granite intrusions, are found. It is not believed that the original diorite or granite can be very old; it is Mesozoic, probably. These various deep-seated and intrusive rocks are described in detail in the chapter on Petrography.

MESOZOIC (?) SEDIMENTS

Above the igneous complex and below the well-marked Tertiary there are at least two definite and easily recognizable formations, the Baruyen and the Kaal, which are exceedingly interesting, in as much as their position is more or less problematic. In view of Becker's statement in 1901 that pre-Tertiary strata are entirely unknown in the Philippine Islands, these become doubly interesting. I cannot say which is the older.

THE BARUYEN FORMATION (RADIOLARIAN CHERT AND JASPER)

This formation was first discovered by me, on the Dungon-Dungon estate on Baruyen River, Ilocos Norte Province, in 1906, and its name is derived from the name of the river. I stated some years ago:(558)

It is perhaps the most interesting of any with which this paper deals. It is exceedingly limited in its outcroppings and quite variable in its phases, never being encountered as a continuous formation, but only as isolated outcrops, which reveal little or nothing as to its position [geologic relationship].

On the left bank of the Baruyen River, about 200 feet up the slope, seemingly projecting out of the talus of a hill which I know to have a serpentine core, is an outcropping of this formation; here it appears to possess more the character of a slate, the fissile slabs varying in thickness from 5 millimeters to several centimeters. It is of a dirty red color, fine grained and compact. The slabs are exceedingly hard, but easily break off with a ringing sound. In the Caraon River this formation is very much brecciated, but the angular fragments have been firmly recemented. Float bowlders were seen in this same stream; they are wholly without structure and in color are a brilliant red, resembling very much the jasper associated with the hematite deposits in Michigan and Minnesota in the United States. The resemblance of some phases of this formation to the radiolarian chert of the San Francisco peninsula which I have seen, also led me to make some sections, with the following results:

DESCRIPTION OF THE SECTIONS.

In thin section this rock is seen to consist of a fine-grained, amorphous groundmass of chalcedonic silica, copiously stained with oxide of iron, with almost innumerable round and oval areas which are more or less clear. In ordinary light the whole section resembles sections of some of the radiolarian cherts of the San Francisco peninsula, to judge from my memory of them and from descriptions.

Between crossed nicols these areas are seen to be filled with a doubly refracting material which often exhibits undulating extinction, and which is in a more or less granulated condition; by using a higher power (number 4 objective, 3 ocular), it is clearly evident that this granulated material, with every optical character of chalcedonic silica, constitutes both the groundmass and the clear areas. * * *

I believe that these clear spaces in the Ilocos Norte slides do not represent individual casts, for I find no trace of "latticework" and but little to compare with the spines found in the California cherts; in fact, I think these clear, circular and oval areas represent pores in the tests of such Nasselarians as *Podocrytis*, *Bothryocampe*, etc.; as yet I have been unable to make any specific determinations from these slides.

In specimens of chert from Panay and Balabac Islands I later identified the genera *Cenosphaera* and *Dictyomitra*,(593) which are also found in the radiolarian cherts of the Franciscan formation in California and Oregon.

K. Martin * and Molengraaff † have found similar cherts in more or less the same stratigraphic positions in the Moluccas

* Reissen in den Molukken, Geolog. Teil. Leyden (1902) 164.

† Geological Explorations in Central Borneo (1902) 414 and 415.

and Borneo, respectively. The so-called "Danau formation" of central Borneo is described by Molengraaff as follows:

C. *The Danau formation.*

FORMATION OF THE GREAT LAKES.

Under the name of Danau formation I comprise a system of deposits, which I saw for the first time typically developed in the area of the great lakes and in the hilly district bordering the north side of these lakes. The constituent rocks are diabase tuff, diabase, diabase-porphyrite, quartzite, chert, jasper, hornstone, clay-slate, and sandstone. The most characteristic, the leading rocks, in this formation are a silicified and partly serpentinized diabase-tuff, which I have called Poelau Melaioe rock, and jasper. In all places where they were found, the jasper and hornstone proved to contain many Radiolaria, and these organisms were also found in many places in the cherts and occasionally in the diabase-tuff.

The examination of these Radiolaria has revealed that these deposits have a pre-Cretaceous, probably Jurassic age.

The strata of this formation are almost everywhere folded and consequently tilted, but hardly ever so strongly disturbed as the strata of the old slate-formation. Neither are they, like these latter, intersected with numberless quartz veins.

Without any doubt the most interesting rocks in this formation are the chert, jasper, hornstone, and diabase-tuff with Radiolaria. The jasper and hornstone in particular consist in many places almost exclusively of closely packed tests of Radiolaria, between which a few spicula of sponges may be seen, all joined together by a siliceous cement. The amount of silica contained in such a hornstone with Radiolaria from the Boengan river was not less than 97%. I found jasper with Radiolaria in various places in the hilly country to the north of the lakes, and later on again, much further eastward, in the extension of the line of strike of the above-named strata along the Upper Kapoewas, the Boengan, and even as far as the boundary between West and East Borneo, altogether over a distance of fully 230 kilometers. The character of the rock remains unchanged over that distance and the beds are always folded with a constant east to west strike. I feel justified in maintaining that these jaspers and hornstones with Radiolaria are deep-sea deposits, formed most probably at a considerable distance from a mainland of any importance. They consist almost exclusively of the tests of pelagic organisms. Now this in itself is no conclusive proof that they must be oceanic deposits, for we know that in certain localities close to the coast where, through peculiar conditions, the deposition of terrigenous materials on the ocean floor was entirely or almost entirely prevented, even at a short distance from the shore, deposits are found which may be composed exclusively of remains of pelagic living organisms. In the case here under consideration, however, the peculiar conditions just mentioned would have to extend along the coast for a distance of at least 230 kilometers which would be altogether too unlikely to happen. The fact that these cherts and jaspers consist almost exclusively of tests of Radiolaria, stamps them as deep-sea deposits; their great horizontal extension with perfectly uni-

form petrographical and paleontological characters stamps them as oceanic deposits. We may therefore conclude from them that in the pre-Cretaceous age, when these deposits were formed, this portion of Borneo was the floor of a deep sea, far away from any land, and this in itself is an important fact.

There seems to be little doubt that these are all to be correlated and, in as much as several authorities have agreed in referring these provisionally to the Jurassic, the same assignment here can be made.

THE KAAL FORMATION

In several localities in the Archipelago unconformably below the Tertiary sediments there are argillites, some of which are almost true slates. Some of these are moderately soft and reddish, while others are dense, hard, and nearly black. These metamorphic, slaty rocks are obviously unconformably beneath the unaltered Tertiary sediments exposed in the vicinity. No fossils have ever been found in them, and so we are at a loss as to their true position in the geologic column.

It is thought that these should be correlated with the "old slates" of Borneo which, according to Molengraaff, are characterized by the frequent occurrence of phyllitic clay slate with silky luster. There the strata of this clay slate alternate with beds of sandstone, graywacke, graywacke slate, and quartzite. Very excellent examples of similar silky phyllites have been found at Tacunan and Misamis, Mindanao.

The type locality of this formation is on Kaal Creek, Masbate, and was discovered and described by H. G. Ferguson.

He says:(274)

> This series of sedimentary rocks outcrops in an irregular band in the western part of the area, running north from the western flank of Mount Vil-lon for about 6 kilometers to a point east of Mount Aroroy, and occurs farther north in irregular areas near the Aroroy quartz diorite formation. These sediments everywhere are the least resistant of the rocks found in the area, and hence are encountered only in comparatively rare outcrops, for the most part in the stream beds. Between Kaal Creek and Mount Vil-lon there is a small plain at about 50 meters elevation, where boulders of psilomelane are found on the surface. Prospecting has shown that the rock here is a very fine-grained, firm, red slate, without traces of banding, containing psilomelane in lenses parallel to the slaty cleavage. A similar red slate with manganese is found farther north, east of the junction of Balangting Creek with the Guinobatan River, and also, on the opposite side of the Guinobatan above the gorge, but here without the manganese. Several outcrops of a dark slate are found in Kaal Creek itself and its two small tributaries. As a rule, this is faintly banded, showing poorly marked narrow bands of dark and slightly lighter material. The

strikes and dips are constantly changing, suggesting great contortion, but as a general rule, where bedding is observable in the rocks of this formation, the strike is northeasterly, and the dips, although extremely variable, are for the greater part steep to the northwest. This darker slate almost invariably is lined with a minute network of quartz and calcite veins, generally not over one centimeter in width and grading down to microscopic veinlets. Much of the slate found in irregular areas on Lubigan and Ambulong Creeks is similar to this. Another phase found in the same localities is a fine-grained, dark purple slate, very similar, except in color, to the red slates east of Kaal Creek. The outcrop of the Kaal formation on the coast, west of the village of Aroroy, and other outcrops east of Mount Aroroy show a graywacke rather than a slate. In the latter locality a grit or coarse-grained sandstone occurs, the pebbles of which, where large enough to be seen, all seem distorted; as far as could be discovered they are composed entirely of sedimentary rock, apparently a fine-grained, dark slate. No pebbles of igneous rock were found anywhere, nor did there appear to be any phase of this formation which might be interpreted as the basal conglomerate of the series. The most interesting outcrop of this formation occurs on the point forming the western corner of Buyuan Bay; here a dark slate, similar to that found in Kaal Creek is seen to be intruded by a small stringer of quartz diorite. Not far from this the slate appears to be in contact with a larger mass of diorite, although the evidence of intrusion is not so clear as in the previous case.

In the vicinity of Lubigan and Ambulong Creeks the slate is frequently cut by dikes of the fine-grained igneous rocks which have been grouped together in the Panique formation. The slate is clearly older than the latter, and it is reasonable to conclude that the Kaal is the oldest formation here exposed. Of course, the intrusion by the diorite of a slate similar to that of the main sedimentary mass is not of itself absolute proof, but were the slate not older than the diorite it would be strange if somewhere a basal conglomerate containing diorite pebbles, were not found. Little can be said as to the absolute age of the Kaal formation. No fossils have been found, but judging from its position, its extreme contortion and considerable metamorphism, it is my belief that it may be classed provisionally as pre-Tertiary, the earliest Miocene shales of the Port Barrera formation.

It may be that we have in the Philippines, as in Borneo, an older and a younger slate, since there is certainly a much older-looking and more-indurated variety and a softer, more-calcareous kind. Recently, on Cebu, I located some of the latter type along the tramway to the Uling coal mines on the eastern slopes of the cordillera. These were not unlike some phases of the Cretaceous on the west coast of the United States. Diligent search, however, did not disclose any fossils, so the matter must for the present be left in doubt.

In the Kaal formation, on Masbate Island, I recently examined a fairly extensive lens of very high-grade pyrolusite. This lens

was interbedded and dipping with the formation. It was about 2 meters thick and over 100 meters long. It dips 50° east and strikes north and south.

In the Paracale gold district, at the Tumbaga mine, there is a body of dark slatelike rock, which is not true slate but merely an indurated shale. It is highly fossiliferous, but unfortunately the fossils are all casts of rather small and not particularly diagnostic forms. They are, without much doubt, Tertiary forms. This body of "slate" is about 10 meters thick and carries calcite stringers exceedingly rich in gold. This formation might be another example of the "younger slate."

PRE-TERTIARY INTRUSIVES AND OTHER ROCKS

Of intrusive igneous rocks, older than the Tertiary, there are at least two types about which we may be fairly certain. Ferguson describes the Aroroy quartz diorite which he found in Masbate as intrusive into the Kaal formation. It is my opinion that the ore deposits in Masbate, as in Benguet, are intimately related to this intrusion.

In Ilocos Norte and other parts of the Archipelago there are pyroxenites and serpentinized rocks of this and related types, which from their association seem very clearly to belong in this part of the column. Diorites, quartz diorites, and granite are the principal plutonic rocks in the basal complex. There may be others, andesites and basalts, but of these I am not so certain. These are described in the chapter on Petrography.

BASAL CONGLOMERATE

At the base of the Tertiary series there is a basal conglomerate, of varying thickness, containing pebbles of diorite, andesite, schist, slate, and fragments of practically all the older rocks occurring stratigraphically below it.

Along Agno River, in Luzon, there are great beds of conglomerate which von Drasche first referred to as "primitive" and, later, as Paleozoic. Abella was the first to question the age assigned to these beds and he showed that the upper beds, chiefly sandstone, contained lignite and comparatively recent fossils. Becker was tempted to correlate these with the Eocene "breccia stage" of Java, but did not definitely do so. It seems he suggested that these conglomerates and coarse sandstones belong at the base of the Miocene or Oligocene.

In Bued River Cañon conglomerates several hundred meters thick can be seen dipping at about 25° southeast which I first

correlated with the Agno beds and placed at the bottom of the Tertiary series. Recently, Dickerson and I studied this formation in Bued River Cañon and found fragments of what appeared to be Malumbang limestone with fossil corals. If they really came from the Malumbang (Pliocene), this formation would be a more recent deposit. To complicate matters a small *Pecten* was found in the matrix, indicating marine conditions. This is all in keeping with the great elevation of Luzon since Pliocene times.

There is, nevertheless, a well-defined basal conglomerate in many parts of the Archipelago at the base of the coal measures. Plate 1 shows the lower coal-measure shales in contact with the basal conglomerate in Suqui Creek in the Compostela region of Cebu.

BASAL TERTIARY

Although Abella and K. Martin concurred in the opinion that the Eocene is represented in the Philippines, based on Richthofen's determination of *Nummulites*, in 1907 I showed that these were *Orbitoides* (*Lepidocyclina*). Dickerson, in his chapter on Paleontology, also shows the absence of fossil evidence, and we have none from the stratigraphic side. In fact, I have shown that in Cebu the lower coal measures abut directly against the basal conglomerate and igneous complex. On the basis of the fauna, these coal measures are Miocene, certainly not older than Oligocene.

Abella based his correlation upon the erroneous determinations of foraminiferal material by MacPherson who thought he recognized *Nummulites*. What he thought were *Nummulites* were evidently orbitoidal forms, which are plentiful in Cebu; no Eocene *Nummulites* has yet been found in the Philippines. K. Martin merely accepted the statements of the other authors. Of course, he was also influenced by the general similarity between the fossil fauna of Java and that of the Philippines, as well as by the fact that the Eocene has been recognized in Java; and so, by indirection, he doubtless came to the viewpoint that the Eocene must surely be found in the Philippines, and, of course, it may yet be found here.

In Borneo the Eocene, according to Molengraaff, is represented by two important facies; namely, a graywacke and limestone facies with *Nummulites* and stellate *Orbitoides*, and a brackish-water facies.

In Java a good Eocene fauna has been found; nothing that resembles it has been recognized in the Philippines.

In specimens of limestone furnished by me, some years ago, Douvillé found one form that he determined as *Nummulites subniasi* (discussed in greater detail by Dickerson in the chapter on Paleontology), which he referred to the Oligocene, but it is quite likely that it is not so old. Furthermore, this limestone was collected by me from drill cores on Batan Island. It is quite likely that it belongs not to the Oligocene but to the Vigo (lower or middle Miocene).

MIOCENE BEDS

VIGO (MIDDLE MIOCENE)

Next in order above the basal conglomerate are the great Miocene beds, which comprise the dominant group of sedimentary rocks in the Philippines. In the middle Miocene there are two distinct subdivisions, in part contemporaneous, judging from the fossils found associated with them; one of these I call the Batan formation, the other the Vigo formation. The first named consists of the coal measures of the Archipelago, and the second is the petroliferous horizon and is chiefly shale. The former takes its name from the type locality on Batan Island, Albay Province, Luzon, the latter from Vigo River on Bondoc Peninsula, Tayabas Province, Luzon. As there is some reason for believing that the Vigo shales generally lie above the coal measures, as they clearly do in Cebu, the coal measures will be described first.

THE BATAN FORMATION

The Batan formation consists of alternating gray shales, grits, sandstone, and coal seams, altogether aggregating several hundred meters of strata. This series dips at various angles from being nearly flat on the east end of the island to as much as 45° to 50° on the west end, and the coal seams are invariably of higher quality wherever the dip becomes very pronounced; that is, the coal contains a greater percentage of fixed carbon and less water and ash.

As there are better sections and more exposures in the coal fields of Cebu, I will draw largely upon that island for my description. In an early paper(561) on Cebu I had this to say of the coal measures:

> I have divided the coal measures into two subdivisions for purposes of convenience in description, although in the field I have found no sharp line between these. The lower part of the measures consists of gray

shales, the upper portion of a coarse, gray sandstone. There are five [only four commercial] coal seams. * * *

The shales, as this stream (the Suqui Creek, Compostela field, Cebu) is ascended, become more and more coarse until the coal seams are encountered where a grit appears. There are about 60 or 100 centimeters (2 or 3 feet) of clay and shale, just above the "Enriqueta" vein, then the coarse gray sandstone comes in, and from there on up to the base of the limestone all outcrops (which are very few indeed) show sandstone. This sandstone in its composition very clearly demonstrates that it was largely derived from the igneous material near at hand and we may infer that the only high land at the time of its formation consisted of the diorite and greenstone hills which stood above and immediately to the westward of the tidal swamps in which the coal was forming. We can estimate the thickness of the sandstone only approximately, but considering the outcrops on the slopes of Mount Licos, I believe it to be not over 150 meters (500 feet). It is very improbable that there is an unconformity between the shales and the sandstone. Numerous observations of the strike and dip of these formations show the strike in general to vary from N. 27° E. to N. 55° E. and the dip anywhere from 20° to 90° SE.

In other parts of Cebu one finds the clayey *Lepidocyclina* limestone coming in as an uppermost member of the coal measures. This is probably the "Nummulitic limestone" of Abella. Abella(11) has a very valuable summary of the stratigraphy of Cebu including the coal measures, which is here given in somewhat abbreviated form (from above downward):

1. Alluvial shales or sands, tuffs, and concretionary limestones, Pleistocene and Recent.
2. Coralliferous limestones, Pliocene.
3. Shales and marls, sandstones and conglomerates, compact limestone with some beds of lignite.
4. Volcanic rocks (intrusive and extrusive).

The Batan formation is widely distributed over the Archipelago, from Mindanao to Cagayan Valley and from Batan Island to Negros. However, the best development is found in the type locality and on Cebu.

The chief index fossil in the Batan fauna is, of course, *Vicarya callosa* Jenkins, the best-known and most-characteristic form in the middle Tertiary of the Far East. Further mention of this is made in the chapter on Paleontology.

Structure.—Although the coal measures are widely distributed over the Archipelago, it seems that they were deposited in a number of separate small basins with more or less different conditions of sedimentation in each; therefore, any attempt to correlate individual seams over too widely separated areas would be difficult and hazardous.

One condition of sedimentation which seems to have prevailed at the time of formation of the coal measures is of the greatest economic importance, since it has affected the persistence of the coal seams. It seems pretty clear that since the earliest Tertiary there have been archipelagic conditions and, therefore, there has been what we now find—great diversity in rainfall. Couple this fact with the torrential type of precipitation and the result is great irregularity in sedimentation, so that it is only natural to find lack of both persistence and uniformity in coal seams.

Geologists who go into the Malay region for the first time should not assume too much from what they may find in a given locality. Cuts along a stream may and usually do show a totally different section a half kilometer away, not only in structure but also in lithology.

THE CEBU LIMESTONE

In the upper part of the coal measures and below the shales where there is no coal there is a blue-gray, clayey, heavily bedded limestone which might, from the characteristic fossils in it, be called the *Lepidocyclina* limestone, with large forms, 2 centimeters or more in diameter, of the foraminifer known as *Lepidocyclina richthofeni*. This limestone is about 5 meters thick and is conformable with the coal-measure sandstone. It is apparently free from corals, is easily distinguished from the overlying Malumbang limestones, and was clearly formed in deeper water. This formation is one of the most easily identified horizons and makes a good key formation for use in working out the stratigraphy of any new region in the Philippines.

VIGO SHALE (MIDDLE MIOCENE)

The Vigo shale in Bondoc Peninsula at its type locality has, according to Pratt, three members. The lowest consists of gray shale, black shale, yellow and brown sandy shale, and sandstone interbedded; above this is the Bacau stage, consisting of massive or imperfectly bedded, bluish or black shale with minor sandy zones (the principal oil seeps are associated with this stage); the third, the uppermost, member consists of sandstones and fine sandy conglomerate in alternate beds.

Pratt and Smith's detailed description of the Vigo shale series is as follows:(506)

Vigo shale.—The base of the Canguinsa sandstone is marked by an unconformity, which is partly of a mechanical nature, but may represent also a period during which the underlying formation, the Vigo shale, was

subjected to erosion. The subject of unconformities is discussed in connection with the geologic structure, page 337.

The Vigo shale is the most extensive and the most uniform series in the stratigraphic column of Bondoc Peninsula. The beds belonging to this formation, although they are closely related in type to some of the overlying beds, constitute a separate stratigraphic division which is readily distinguished.

The type exposures in the valley of Vigo River consist of fine-grained shale and sandy shale interstratified in thin regular beds from 5 to 10 centimeters in thickness. Occasional beds of sandstone occur varying from 10 centimeters to 1 meter in thickness. The fine-grained shale is gray, blue, or black, and is made up almost entirely of clay. The sandstone is gray or brown, and consists of uniform, medium-sized, not completely rounded grains of quartz, diorite, andesite, and metamorphic rocks. The sandy shale is yellow or brown and of intermediate composition.

There is an apparent transition from east to west in the character of the Vigo shale. In the eastern limb of the Central anticline, exposed in the Valley of Vigo River, the formation is predominately shale throughout, sandstone occurring only at intervals. In the western limb shale predominates in the exposure near the axis only, that is, the lower part of the series. Farther to the west the sandstone beds increase in number, until in the upper horizons they become more prominent than the shale. The grain-size likewise increases in the upper beds, and small pebbles occur, forming layers of sandy conglomerate.

The blue or black, fine-grained shale in the Vigo formation usually emits a slight odor of light oils upon fresh fracture, and in some outcrops is highly petroliferous. The material loses this odor and assumes a light gray color after it has been exposed to the air and has become thoroughly dry. The petroliferous shale forms a loosely defined stage in the upper part of the Vigo, which will be referred to as the Bacau stage, although it cannot be sharply delimited.

The Bacau stage * contains fewer beds of sandstone than the Vigo shale proper, and the bedding planes are often less distinct; thus, exposures at Bacau and Sili have the appearance of massive banks of compact, hardened clay, which are sandy in subordinate, irregular zones only. To material of this character the ordinary definition of shale which stipulates a fissile or laminated texture does not apply strictly, but the term is convenient and, employed in a broad sense, is preferable to "clay" or "clay-shale" in describing the rocks in the Bacau stage. The shale weathers into concretion-like ellipsoidal pieces from which concentric layers split off, and break into small fragments with conchoidal surfaces. The manner of weathering distinguishes the petroliferous beds from other fine-grained layers in the Vigo which are fissile and split into flakes upon disintegration.

Beds analogous in character to those in the Bacau stage are found throughout the Vigo shale, but the Bacau stage proper appears to be confined to a zone from 50 to 75 meters thick in the upper portion. In

* Dickerson says that this may not be a true stage, but merely a local facies, and its position is not uppermost.—W. D. S.

the eastern half of the field, the Canguinsa sandstone overlies the Bacau stage in a majority of exposures. Occasionally (section on Dumalog Creek, Table XIII, page 333; and on Bahay River, Table X, page 320), sandstone and fine conglomerate, which are evidently a part of the Vigo series, occur above the Bacau stage. In the western part of the peninsula sandy conglomerate is found near the top of the Vigo formation. These overlying beds may be always present above the Bacau stage, but concealed generally by an overlap of the unconformable Canguinsa sandstone. The sandstone and conglomerate in the upper part of the Vigo shale are generally micaceous, and show many carbonized leaf-impressions. In the southwestern part of the field, large pieces of silicified wood were observed in the conglomerate, and on Bunsaua Creek a bed of lignite 20 centimeters thick occurs in the shale below this horizon. * * *

The thickness of the Vigo shale is unknown. An apparent thickness of about 1,400 meters is revealed in the Matataha River section, the section on Malipa Creek in the southern limb of the Malipa anticline shows 800 meters of Vigo shale, and the section on Guinhalinan River indicates 600 meters. None of these sections exposes the base of the formation. The apparent thickness of the sections as measured along the outcrop may be in excess of the actual thickness as a result of superficial expansion of the beds or of the repetition of beds from faulting or close folding.

Distribution of the Vigo.—The Vigo shale is widespread in the Philippines, from Luzon to Mindanao, but it is particularly well developed in the Visayas, and undoubtedly is the same as the oil-bearing formation of the Dutch East Indies.

Structure.—In Tayabas, Cebu, and Mindanao I observed the Vigo shale to be considerably folded and often faulted. It is thrown into pronounced folds, anticlines, and synclines, as in Tayabas, while in central Mindanao it is so badly disturbed that it is found in many places standing on end. The characteristic Vigo fossils are described in the chapter on Paleontology.

CANGUINSA SANDSTONE

Above the Vigo and with an unconformity between, marked by mechanical discordance, is the Canguinsa sandstone which also has been described by Pratt and Smith.(506)

Canguinsa sandstone.—The Canguinsa sandstone is a close-grained, gray or blue rock to which the term sandstone applies in a general way. It is distinguished from the Cudiapi sandstone by its massive or less perfectly bedded appearance and by the considerable proportion of clay which characterizes it. The upper portion is usually a soft, clayey sandstone, imperfectly bedded and occasionally close jointed. This sandstone is calcareous, and several exposures on the upper part of the Canguinsa River are concretionary. The concretions are aligned so as to lend a bedded appearance to the exposure. The concretionary sandstone was not observed to be of general distribution.

Toward the base of the formation either a typical sandstone or an indurated massive or jointed clay is encountered. Both sandstone and clay

occur in heavy banks from 3 to 6 meters thick, and both are slightly calcareous. The sandstone facies in the basal portion is deep blue on fresh exposure, but weathered surfaces are gray or brown. Ordinarily, it is of medium-grain size, and shows little evidence of bedding. The clay is also blue when freshly exposed, and becomes gray upon weathering; it is fine and compact, but not bedded. Some of the rocks which have been classed as marl in Java and Sumatra are probably similar to the slightly calcareous clayey zone in the Canguinsa sandstone.

The clay and sandstone banks in the base of the formation are fossiliferous and sometimes contain myriads of small shells. The fossils are often greasy and appear to be well preserved, but in reality they are very fragile, and can be removed entire only with care.

In the section on lower Bahay River, the Canguinsa sandstone includes a few meters of limestone and conglomerate. On Mount Maglihi and Mount Morabi limestone which contains coarse sand and small pebbles of diorite, quartz, and andesite is present in the Canguinsa sandstone, but no conglomerate was observed. In the lower part of the gorge on Canguinsa River, also, a subordinate thickness of limestone was found in the Canguinsa sandstone. * * *

The thickness of the Canguinsa sandstone varies from 50 to 160 meters. Although it occurs unconformably over the Vigo shale, the contact between the two formations is found always near the same horizon in the Vigo shale, and the base of the Canguinsa sandstone serves as a datum for rough correlation.

The Canguinsa sandstone is not encountered in large areas, but occurs in steep slopes along streams where it has been protected from erosion by the overlying Malumbang series. * * *

No definite age determination can be made from the fossils in the Canguinsa sandstone proper. The fossils in the included limestone, however, are well known and have been used in correlation by various authorities. From their presence it is concluded that the Canguinsa sandstone should be placed in the middle Miocene, extending, perhaps, into the lower Miocene.

The Canguinsa sandstone occurs immediately above the principal known oil horizon. It is not porous enough to afford a reservoir in which oil might accumulate, and no oil has been observed in it. Because of its compact nature on the other hand, it would tend to confine any oil collecting below it. At several promising drilling sites the Canguinsa sandstone must be drilled through before the petroleum zone is encountered.

I have thought that this sandstone might be the equivalent of the coarse heavy-bedded sandstone in the Batan or coal-measure series below, as the Cebu limestone with the larger lepidocyclines is associated with a coarse sandstone of the coal measures.

ALPACO * (UPPER MIOCENE)

Well above the lignitic series (and probably the Vigo also) of Cebu, and below the coral limestone portion of the Malum-

* Alpaco is west of Naga on the eastern side of Cebu Island.

bang, there is a marl member to which I have given the name Alpaco from the type locality near Mount Alpaco on Cebu Island. This was first noted by Abella and referred by him to the Quaternary. From fossils contained therein K. Martin considered that it could not be younger than the Miocene (he noted *Orbitoides*, and I have identified *Cyclolites*). The whole matter is somewhat in confusion; and Becker, who commented at great length on this particular member, could not decide just where to place it. From its position I judge it to be somewhere near the top of the Miocene, and it may be part of the Malumbang (Pliocéne).

Abella's description of it is as follows:

> Surrounding the rocks hitherto described on every side, lies an essentially calcareous terrane, which, in general terms, may be said to pass over into the coral reefs on the coast and to rise toward the interior, forming masses as high as those in Mount Mangilao. In addition to the limestones, there is exposed at many points beneath them a bed of marl, more or less argillaceous, which must be referred to this formation, since its stratification is always concordant with the limestone and it contains fossils similar to those found in the limestone. This bed can only be seen toward the central portion of the island and toward the south, in its widest portion, generally appearing at the bottom of the deepest ravines. At Magdagoog, in the district of Consolación, which is on the eastern coast, we found such a marl dipping at 20° to the southeast. It is grayish white, and almost plastic when extracted but hardens rapidly on exposure. Among the many fossils found in it, in addition to the species which are mentioned later, we found the genera *Cancer*, *Dolium*, and *Cyclolites*. This *Cyclolites* we also found in the Compostela road where it crosses the first hills near the coast. * * * At Mount Alpacó, again, appears another bed of gray fossiliferous marl, analogous to that at Magdagoog, but in circumstances which are entirely exceptional in the matter of position. In fact, it is found isolated, overlying the mass of compactly crystalline limestone of the old road to the mines, and seemingly with a dip of 50° to the northeast. In it we collected a large portion of the well-preserved fossils, which, when determined, as we shall see further on, have turned out to be identical with living species, demonstrating the recent age of the bed. Moreover, we have found other marls, identical in composition and containing similar fossils, always lying under the limestones with conformable stratification, not only at the bottom of the beds of the rivers Bairan and Sapangdacó, but also in the gulch Jaguimit of the Pandan Valley so close by (the Alpacó locality). We must, therefore, rationally suppose, as we have previously indicated, that some landslide or other local convulsion has brought this marl bed into a certain sort of association with the nummulitic limestone of Alpacó, at a distance from the coarse limestones of the coast, to which formation it must be referred.

In about this position in other parts of Cebu Pratt has noted beds of tuff, although at Alpaco, the type locality, marl and not

tuff is seen. On account of the stratigraphic position with reference to the coral limestone above, I have placed these two together on the stratigraphic chart.

This marl is being used as one of the ingredients in the mix for Portland cement at the mill established at Naga, 3 or 4 kilometers from Alpaco, Cebu.

ZAMBOANGA FORMATION (PRE-PLIOCENE IN PART)

A very widespread formation in the Philippines is a volcanic agglomerate generally of andesitic composition which in places blankets the underlying Tertiary sediments over great areas and makes it very difficult to explore them. From the field relations I judge that this formation is older than the Malumbang, but there are undoubtedly some agglomerates that are much younger as well. A typical exposure is shown on Plate 18, fig. 1, from Zamboanga Peninsula, Mindanao. Of course, the thickness of such a deposit is very variable and difficult to estimate. In places it appears to exceed 150 meters. The typical deposit consists of large and small angular blocks and fragments of andesite firmly cemented in a lava or mud matrix.

THE MALUMBANG FORMATION (PLIOCENE)

The type locality of this formation is in Bondoc Peninsula, but perhaps the best locality in which to study it is on Cebu, where it covers many square kilometers of country. There is a marked unconformity between it and the Miocene formations just described. The Malumbang formation in Bondoc has three principal members; namely, the uppermost (coral) limestone facies, a yellow sandstone, and a lower white massive limestone. This formation has a thickness of from 100 to 300 meters in Bondoc, but in Cebu it is much greater.

I quote here Pratt and Smith's detailed description.(506)

Malumbang series.—The Malumbang series at the top of the column of folded strata consists of the Cudiapi sandstone, which is generally, but not invariably, included between limestones. The limestones are sandy and at many places are either missing or cannot be distinguished from the sandstone which is usually calcareous. They are brownish yellow to white, and generally massive or in thick poorly defined beds. Locally, and usually in the sandy facies, the limestone is bedded, the individual layers averaging from 15 to 30 centimeters thick.

The Upper limestone is generally coralline, although the transition between it and the calcareous sandstone below is gradual. At places on the coast where it is not highly inclined, it cannot be delimited from the recently raised reefs. In representative exposures it shows a thickness of about 30 meters.

The Cudiapi sandstone is named from a type occurrence in the summit of South Cudiapi Mountain. In many places it exhibits alternate beds of different thicknesses; the thinner beds are more calcareous and harder than the intervening thicker beds, and are more resistant to weathering so that the outcrops are characterized by the protruding edges of the thin beds. Where the Lower limestone is missing, the Cudiapi sandstone cannot be separated sharply from the underlying Canguinsa sandstone. The estimated thickness of the Cudiapi sandstone ranges from 40 to 135 meters. The exposure on the summit of South Cudiapi Mountain is about 80 meters thick.

The Lower limestone is generally less than 20 meters thick. It is harder and more compact than the Upper limestone, and is more frequently bedded. In other respects, the limestones of the two horizons are similar and hardly to be distinguished.

On Mount Cambagaco, in the stratigraphic position of the Lower limestone, a rock of unusual appearance is to be seen. It is composed mainly of limestone concretions, 1 centimeter or more in diameter, which have a concentric structure. The concretions lie close together in a cement which is also calcareous, giving the rocks a magnified oölitic texture. This particular variety of the Lower limestone was not observed outside the one vicinity near Mount Cambagaco.

The Malumbang series attains its greatest development in the vicinity of Malumbang Plain extending north beyond Balinsog Hill, south through Mount Banaba and Mount Guinamuan, and southwest to Tala and Sili with a detached area farther south on top of Bondoc Head (see geologic map). The lower two members are found in the Cudiapi Range, while the ridge along the east coast consists of a single limestone (Lower ?) overlying the Vigo shale with a concealed interval between. San Narciso Peninsula is covered by the Upper limestone.

The Cudiapi sandstone, the principal rock in the Malumbang series, might be called a marly sandstone, and the limestones are likewise often sandy or clayey. Shale is not present, but some exposures of the Cudiapi sandstone are argillaceous.

No indications of petroleum have been observed in the Malumbang series. It is above the horizon at which oil seeps occur, and bears on the possible petroleum industry only in the fact that it must be drilled through before the petroliferous zones can be explored in parts of the promising territory.

In many parts of the Archipelago there is a marl phase of the Malumbang that is very characteristic, and in places it is very fossiliferous. One locality where this facies is well exhibited is in the gorge of Malitabug River, a wild mountain tributary of the Rio Grande de Cotabato in Mindanao. This marl is soft and creamy white and very rich in the casts of pelecypods of the genera *Arca, Cardium, Tellina, Cytherea?*, and others. Plate 2 shows a shale or agglomerate phase of the Malumbang limestone in Cebu, exposed on Danao River.

This formation, particularly the upper coral-limestone member, is widely distributed throughout the Archipelago and is found at elevations varying from near sea level to 1,950 meters (Mount Santo Tomas, near Baguio). Its altitude is usually that of moderate inclination, and in many places it is markedly faulted.

Owing to solution, the terrane where this formation occurs is very pronouncedly rough, and in certain localities there are some remarkable erosion effects. These are best seen, perhaps, at Sagada, Mountain Province, Luzon (Plate 3).

One of the most remarkable features of this formation is the reefs of coral near Baguio, particularly in Trinidad Gap where fragments in great profusion of *Porites* stems, *Astrea,* and other living reef genera are to be seen.

This recalls the "coral atoll" explanation, by von Drasche, of Trinidad Valley just north of Baguio. I examined this some years ago, and again recently in company with Dickerson, and we both decided that the valley is an erosion feature and that there is no indication of an atoll there. Apparently, there is no reef structure other than the local patches of reef. The limestone beds dip gently about 10° to 15° northwest.

The lower limestone facies of this formation is especially well developed in Cebu in the glistening white, hard limestone of Mount Licos, Uling, and other mountains, all prominent landmarks of that island. I have found in the denser lower portion the characteristic *Lithothamnium,* and in the upper coral member many fine corals identical in genera and, in most cases, in species with those now growing in the adjacent seas.

THE GUADALUPE FORMATION

Perhaps the most interesting, as well as one of the most important, deposits of the Pliocene or earliest Pleistocene is the tuff deposit of the Manila plain. Von Drasche, Centeno, Becker, and Adams have each had something to say of this formation; but it remained for me to give it a name, which I supplied from the town of Guadalupe on Pasig River, where there are good exposures of this formation.

As von Drasche's(200) description of this formation is one of the earliest and best I shall quote him, as follows:

> As one goes from Manila along Pasig River, there appears in a short time a brown soft tufflike stone Pozzuolan (trass) or pumice-stone tuff. This material can be separated into one part which is rich in crystal frag-

ments and finely clastic pumiceous material and another which is a pumice conglomerate with fragments of broken volcanic rock mixed with it (agglomerate).

In the first group one finds in the light brown earthy mass numerous feldspars, well-shaped augites, and little fragments of obsidianlike stones besides numberless pieces of scoria. Tuffs of this character are especially well shown in a cut on the left bank of the Pasig near the road.

The finest blocks of this pumice stone occur at Guadalupe on the left bank of the Pasig.

The [trass] is here separated into heavy beds and contains numerous carbonized tree stems and other indeterminable plant remains. One often finds very thin streaks of coal. The distribution of this tuff is extraordinary. The Pasig has carved out its entire bed in this material, and one sees in many places on both banks walls of it as high as ten meters. I traced this formation on the right bank of the river as far as San Mateo. To the north I encountered it as far as San Francisco del Monte. Indeed we shall see later that its source is in Taal Volcano.

Shark and deer teeth have been found in this material, the former from a railroad cut, the latter from a well at a depth of between 81 and 85 meters. Both have been described by Adams. This is one of the most extensively distributed formations in central Luzon. The tuff makes a good though not handsome construction material.

At Sagada, Mountain Province, Luzon, there is a volcanic ash formation which I studied and described in 1914; it appeared to me to be Pleistocene in age as it seemed to overlie the Malumbang (Pliocene) limestone, though it may be interbedded with and hence a part of the Malumbang.

As this tuff, owing to the fossil flora entombed in it, is of great importance in Philippine stratigraphy and geologic history, I shall quote at length from my paper of May, 1915.

As would be expected in a region of formerly great vulcanism, tuff beds are a dominant feature of the sedimentaries. At Sagada, where Father Staunton, of the Sagada Mission, has opened a quarry to secure material for his new church, is perhaps the best section of the tuff beds to be seen anywhere in the province. The face of the quarry is about 15 meters high and reveals the following beds:

1. Soil and loose material.
2. Tuff in heavy beds, 1.5 to 3 meters.
3. Yellow-stained shale, 0.5 meter.
4. Tuff in solid bed with varying texture, 18 meters.
5. Bluish black shaly-looking rock which is very fine-grained, 1 meter.

In this section the strata appear to be nearly horizontal, as the face is approximately along the strike. The dip is about 20° to the southeast. In the shaly portions are great numbers of leaf impressions, some fine specimens of which I secured through the assistance of Mr. McBrust, the engineer of the Sagada Mission. These leaf impressions are so perfect

and so much like some of the living lowland plants that I submitted them to Mr. E. D. Merrill, botanist of the Bureau of Science, for identification. His illuminating notes are inserted here:

"The fossil remains, mostly remarkably clear leaf impressions, all or nearly all, represent species still living in the Philippines at low and medium altitudes, and an examination of the material shows that the forest in the Bontoc locality was a typical mixed dipterocarp forest such as is found to-day in all parts of the Philippines, where primeval vegetation persists, from sea level to an altitude of about 800 meters. None of the species is found to-day within the limits of Bontoc subprovince, and very few of them are to be found in any part of Mountain Province. None of them is found above an altitude of approximately 800 meters, while the present altitude of the fossil-bearing strata is 1,500 meters."

These tuff beds are in all likelihood equivalent to the great series of tuff beds in Java in which *Pithecanthropus erectus* Du Bois was found, and which were once thought to be Pliocene but have recently been shown by Schuster to be Pleistocene.* Schuster bases his conclusions upon the plant remains inclosed in the strata. From other considerations it seems probable that the Philippine deposits are somewhat earlier than the Trinil beds.

The conclusion to be drawn from the presence of these fossil leaves is clearly that there has been very recent and very pronounced elevation in this part of Luzon. It does not signify a change in climate in the Philippine region other than that attendant upon a change of elevation. All the evidence we now have favors the belief that there probably has been little or no regional change in climate throughout the Tertiary and post-Tertiary in this part of the world.

THE PLEISTOCENE

Above the Pliocene series with presumably an unconformity (not always in evidence, due to lack of contacts) come several formations (generally no two can be found in a given locality), of quite diverse nature. I do not know the stratigraphic positions of these relative to each other, but merely give them in the following order: Elevated reefs, marine conglomerates, high-level river deposits (in part auriferous), lateritic iron deposits (in part), and basaltic and andesitic flows and agglomerates.

ELEVATED CORAL REEFS

In many parts of the Philippines, particularly along the present coasts, elevated reefs in three to five terraces exist, which

* Monographie der Fossilen der Pithecanthropus Schichten, Abh. d. k. Bayr. Akad. Wiss. 25 (1911) Abth. 6.

are of Pleistocene and Recent age. In Cebu, as Becker * pointed out twenty years ago, it is possible to start at the living reef fringing that island and walk practically to the crest of the island on coral limestone without a break, save such as is due to erosion; that is to say, since the Pliocene Cebu has been gradually rising from the sea, and as it rose the coral continued to grow outward; so that now the island is almost completely mantled with coral limestone. This has not been a uniform elevation throughout, as the terraces, well developed on the western side near the southern end, will attest.

In central Mindanao, far up the Rio Grande de Cotabato, one finds raised coral reefs which clearly date from the Pleistocene or even early Recent. At Fort Pikit, about 70 kilometers from tidewater, a quarry for road metal has been opened in one of the low hills characteristic of that region. As shown by this quarry and other cuts, these hills, on one of which Fort Pikit, a Constabulary outpost, is built, about 50 meters in elevation above sea level, are almost completely made up of corals and coral débris. Some large heads of *Astrea* and *Meandrina* (*?*) look as fresh and unaltered as if they had just emerged from the sea. It is evident that a great area of the sea occupied much of Cotabato Valley within the late Pleistocene or the early Recent. This material is used for building stone, road surfacing, and lime throughout the Archipelago.

MARINE CONGLOMERATE

Adams thought this formation, which I assign provisionally to the Pleistocene, was contemporaneous with the pyroclastics of the surrounding region and, therefore, must be put into the Pliocene. Adams says of the conglomerates:(21)

> By far the most important area of this formation is to be found on the north and west flanks of the Pico de Loro Mountains to the south of the entrance to Manila Bay. The lower slopes of the mountains descended to the coast gradually and at the shore are cut off abruptly in sea cliffs. In these cliffs the marine conglomerates are well exposed. West of Ternate they are in many respects similar to the beds on Corregidor Island. They were also seen in the cliffs of Carabao and other islands near the shore and in the jagged coast line south, to the vicinity of Nasugbu. In this part of the coast, which is exposed toward the China Sea, they have yielded more readily to erosion, and deep inlets and coves have been formed. The conglomerates are found up to an elevation of about 200 meters north of Nasugbu. The bowlders in the conglomerate are mostly andesitic. The finer materials are in part derived from erosion of igneous rocks, but to a considerable extent they are tufaceous. Some of the

* Dickerson disagrees with Becker in this interpretation.

tufaceous material may have come from the denudation of deposits on the mountains of the western cordillera, but it is probable that much of it is the equivalent of the great tuff area found in the southwestern volcanic region. This is suggested by the fact that the Pico de Loro Mountains on their eastern flank are partially overlaid by water-laid tuffs. Near Ternate and Naic the conglomerates apparently grade into the deposits of water-laid tuffs which have a great extent in the adjacent plains.

Marine conglomerates on the southern end of Mindoro have recently yielded a Miocene (?) fossil; namely, *Carcharodon arnoldi* Jordan. This was found by Mr. G. B. Moody.

BENCH GRAVELS

These marine conglomerates probably have their inland counterparts in some of the high-level river gravels, much as those along the Benguet Road in Bued River Cañon and in various other parts of the Islands. On both flanks of the Zambales * Mountains are great masses of such gravels more or less indurated, but these may be a little younger. Abella,(1) in an account of gold placer mining in Cagayan de Misamis, constantly refers to high-level gravels that were auriferous. These are probably contemporaneous with those already mentioned.

LATERITE

Although it is difficult, perhaps impossible, to delimit the age of this material, and as it is unreasonable to suppose that its formation has not been going on prior to the Recent, it will be discussed in this place. Laterite is a ferruginous red clay, a product of weathering of certain igneous rocks, whose importance was first recognized by the geologists of India; since they called attention to it, it has been noted and described in many countries, particularly within the Tropics.

In the Philippines there is much laterite in various localities at both high and low altitudes. In Surigao Province, northeastern Mindanao, there is the greatest extent of this deposit yet found in the Philippines. In that locality its iron content is such as to make it valuable as an iron ore. This is more fully described in the chapter on Economic Geology.

According to Pratt and Lednicky, who studied this deposit carefully in 1915, "The parent rock in Surigao is subsiliceous in character and is probably a peridotite * * *. The out-

* Mr. Elicaño, on a recent trip to Candelaria and Masinloc, Zambales, found them overlain by Vigo shales. He saw no fossil in the conglomerate, but secured *Mitra javana* and *Globigerina* from the overlying shales. They may be correlated with the Agno conglomerate.

crops which are most widely distributed consist essentially of serpentine." In places this deposit is 20 meters thick.

At Baguio, in the Mountain Province, at an elevation of from 1,200 to 1,500 meters, there is an extensive formation of ferruginous clay which is in part the residual products of limestone weathering and in part decomposed, igneous material. It is a very conspicuous feature of the region and recalls similar deposits characteristic of the southern Appalachian region of the United States.

BASALTIC AND ANDESITIC FLOWS AND AGGLOMERATES

Throughout the Tertiary, and certainly in the Pleistocene, there have been volcanic eruptions, and they continue at intervals to the present time. Although in the past there may have been outpourings of lava, to-day the eruptions are all of the explosive type and all the ejecta are fragmental. It is believed there were both types in the Pleistocene and that many of the volcanic stocks of basalt and andesite date from that period.

RECENT

Many of the deposits of the Recent period are similar to those of the past and many of them are in process of formation. From a study of these formations the mode of origin of the older islands can be inferred. A study of the deposits in process of formation also indicates that many of them are being formed contemporaneously, and so they dovetail into one another, actually, both in space and in time.

Some of the important materials being deposited at the present time in diverse parts of the Archipelago are coral reefs, laterite, talus in the form of landslides, alluvial fans, spring deposits, and sands and silts along the coast. The coral reefs will in the future appear either as raised reefs or, when triturated and recemented, as limestone; the talus slopes will simulate agglomerates; the sands and silts off the coast will make sandstones and shales; the river and coast gravels will form conglomerates; and the loose volcanic ash from volcanoes will make tuffs, and so the story of the past must be largely interpreted in the light of the present.

PETROGRAPHY

Studies relating to the lithology of the Philippine Islands are still more or less fragmentary, and no comprehensive petrographic monograph of the rocks has been attempted. For the purpose of the present study, it will suffice to give an idea of the lithology by means of a number of descriptions of Philippine type rocks. For a lengthier account of the distribution and a more philosophic discussion of some of the important facts pertaining to them the reader is referred to Becker.(50)

Of the past workers in Philippine petrography the most important are: Richthofen,(525) who studied rocks collected here before the miscroscope was perfected and who published a paper in 1862; Roth,(532) who published a paper describing Jagor's specimens in 1873; and von Drasche,(200) whose meager petrographic notes on rocks collected by him in the Philippine Islands appeared in 1876. Among the early investigators in this line Oebbeke,(462) who never visited the Islands but who studied Semper's collections, is also very important; his results were published in a small booklet in 1881. Abella made considerable use of the petrographic microscope in his studies on Panay(11) and Cebu;(12) this was prior to 1898.

Subsequent to 1898 Iddings and Smith have been the largest contributors to the literature on this subject. The former studied a thousand or more slides in the Bureau of Science collections and wrote one general paper,(337) and the latter published several more-local papers, the most important of which is one describing some rocks from Benguet, Mountain Province.(560)

THE IGNEOUS ROCKS

The igneous rocks of the Philippine Islands consist of the general groups that are common elsewhere. They are as follows:

1. The igneous rocks of the recent volcanoes and the worn-down stocks of the older ones, including both extrusives and intrusives. Under the extrusives we have not only massive lavas but also aërial breccias or, rather, volcanic agglomerates and tuffs.

2. The deep-seated igneous rocks, which are those that have been exposed only through long-continued erosion. There is every gradation between these and the extrusives, and in some cases there may be little or no difference in age. These older crystalline massives in the Philippines formerly were thought to be very old, perhaps Archean, but there is no good reason for believing the majority of them to be of greater age than the Mesozoic.

FIRST GROUP OF IGNEOUS ROCKS

Under the first head there are the following principal types, given in the order of their predominance: Andesites, pyroxene andesites, hornblende andesites, hornblende-pyroxene andesites, olivine-bearing pyroxene andesites, hornblende-biotite andesites, basalts, dacites, and leucite tephrites.

ANDESITES

The andesites are by far the commonest of these rocks, and the pyroxene-bearing variety is dominant. Next to it comes hornblende andesite. The andesites form the older parts of the volcanoes, and the basalts generally constitute the later flows.

PYROXENE ANDESITES

These rocks, as a rule, are dark colored, usually dense but often porous, porphyritic, commonly with small phenocrysts. Phenocrysts and groundmass occur generally in equal proportions. A typical specimen collected at Sisiman, Bataan Province, on the north side of the entrance to Manila Bay, is described by Iddings as follows:

* * * A dark-colored sempatic, mediophyric rock; that is, one having many small phenocrysts, about as much in bulk as the groundmass which contains them. The phenocrysts are mostly labradorite, approximately Ab_2An_3, with pronounced zonal structure, the narrow outermost zone being distinctly alkalic. The shapes are those of rectangular prismoid to equant crystals. In size they are seriate; that is, of different sizes, from those of several millimeters to less than 1 millimeter. * * * There are fewer phenocrysts of hypersthene and augite, the former faintly pleochroic in thin section. Augite * * * occasionally surrounds hypersthene. The pyroxene phenocrysts are euhedral [well-faced], with the first and second pinacoids strongly developed. In size they are generally smaller than the largest feldspar. There is considerable magnetite in small crystals. Those inclosed in pyroxene are smaller than others not so inclosed. Some are inclosed in the margin of the feldspar. The groundmass consists of microlites crowded together; rectangular equant [equi-dimensional], also prismoid plagioclase feldspar, prismoid pyroxene,

and equant magnetite; probably with a cementing matrix of colorless glass.

Hypersthene is very common in many of the Philippine andesites (Plate 4, fig. 1).

HORNBLENDE ANDESITE

This rock is found in all parts of the Islands; it forms the summit of Mount Apo and several peaks in the Zambales Range of Luzon. Its habit varies from a rock having large phenocrysts of feldspar, 10 millimeters or more in diameter, and smaller ones of hornblende, to that in which the relations are just the reverse. They are the "trachytes" of the older writers. The disintegration of these rocks with the large, glassy plagioclases produces the Orani and Tarlac sands, the best sands for constructional purposes available for use in Manila. The layman usually mistakes this plagioclase feldspar for quartz, whereas the sands contain little or no quartz. Iddings has described the hornblende andesite used in the Manila breakwater,* which came from Sisiman Point, as follows:

It is sempatic, seriate and mediophyric. The most abundant phenocrysts are labradorite Ab_2An_3, euhedral [well-faced] and subhedral [with less perfect faces]. They possess a narrow outer zone of distinctly more alkalic feldspar, which, however, has noticeably higher refraction than the anhedral [without crystal faces] feldspar of the surrounding groundmass. The hornblende is greenish-brown, but is mostly paramorphosed into aggregates of magnetite and pyroxene. There are few phenocrysts of pyroxene, and relatively large ones of magnetite. The groundmass is holocrystalline [complete crystal outlines], composed of consertal [intergrown] anhedrons of feldspar, in part probably orthoclase, with some quartz. The rock is somewhat altered in parts, and contains calcite [and (?) chalcedony].

This is the variety in which the hornblendes are very large and the feldspars not so prominent. In the rocks from Mounts Apo and Pinatubo the reverse is the case.

TRACHYTES

In the older literature, especially in the writings of von Drasche, trachytes are frequently mentioned; but Becker was of the opinion that some of these were not true trachytes, in which opinion I concur. It is probable that the term was loosely

* After about a dozen years of exposure in this sea wall this massive rock is beginning to spall and crack and will ultimately crumble unless faced with some protecting material.

used. Iddings does not include them in his list of over five hundred rocks examined.

BASALTS

Of this great class of rocks Iddings says:

There are transitions between olivine-bearing pyroxene-andesites and basalts rich in olivine, so there are basalts with the textures found in andesite, and others with texture not developed in andesites. No line can be drawn between these two groups of rocks; and petrographers differ as to the classification of rocks intermediate between basalts and andesites. It happens that the lavas of Mayon and Taal Volcanoes belong in part to these intermediate varieties, which may be called olivine-bearing pyroxene-andesites or andesitic basalts, while other varieties of lava from these volcanoes are normal basalts, with abundant olivine. * * *

Basalt from the floor of the crater of Taal Volcano is dopatic [groundmass dominant], mediophyric [moderately porphyritic], with phenocrysts of subhedral, green augite, having inclusions in zones in some crystals; subhedral equant to tabular labradorite (Ab_2An_3 to Ab_1An_2), zonally developed; and fewer colorless to yellow olivines, altered on the surface of the crystals. The augite and labradorite are anhedral toward each other when in clusters. The olivine in some instances is partly inclosed in augite, with anhedral forms. The groundmass consists of euhedral prismoid plagioclase, with central euhedral prismoid inclusion that has much lower refraction and is isotropic, apparently glass. The plagioclase prismoids have diverse arrangement. There is also much equant anhedral augite, less magnetite, and probably intersertal colorless glass, but the microlites are crowded close together, and the rock may be holocrystalline. * * *

LEUCITIC ROCKS

A dark, fine-grained rock with small, almost circular white areas, 2 or 3 millimeters in diameter, occurs near Aroroy, Masbate. This proves to be analcite, an alteration product of leucite, when examined in thin section. Rarely, the original leucite can be seen.

I have seen very similar-appearing rocks in northern Luzon, but in none of them could I be positive that the small isotropic whitish areas were leucites. The finding of this class of rocks in the Philippines is noteworthy, as potash-bearing rocks apparently are of rare occurrence. Iddings's description follows.

The rock from about 2 kilometers southwest of Aroroy is dark-gray, sempatic, mediophyric, and seriate; the diameters of the phenocrysts varying from 5 millimeters to less than 1 millimeter. They are chiefly euhedral twinned augite, greenish with faint pleochroism, from green to yellow; clusters of equant colorless crystals, and some isolated euhedrons of a mineral which appears to be leucite, possibly altered to analcite, as it does not exhibit birefri[n]gence. There are some small phenocrysts of plagioclase, partly altered and probably alkalic, or calci-alkalic. The augite phenocrysts are zonally developed, with "hour-glass" structure in some

cases. They contain glass inclusions and small crystals of magnetite. Surrounding the phenocrysts, especially the augite, there are dark clusters of minute crystals that extend to various distances into the groundmass. They are needles and minute prismoids of augite in subparallel clusters. In places they seem to be granulated, or coarsely globulitic. With these prismoids are mingled opaque needles, or blades of what appears to be limonite; but from their resemblance to similarly shaped and arranged blades of brown mica, present in closely related rocks of this locality, they may be paramorphic mica. They are in sets, or groups, of parallel prismoids, often at different angles in the matrix, or in fern-like arrangement; a set of minute, parallel blades being crossed by a larger one like a stem.

The clusters of colorless minerals have the form of leucite crystals, are euhedral to subhedral; and in some cases rounded. Some carry minute inclusions, centrally located, less often zonally. In several finer-grained varieties of the rock there are minute, imperfect, skeleton forms characteristic of leucite. The groundmass consists of indistinctly outlined, clouded feldspar, possibly orthoclase in part, besides products of alteration. In the finer-grained variety the prismoid and needle-like alkalic plagioclase is more distinct. There are prismoids of augite, and groups of parallel needles or blades of pale brownish, pleochroic mica.

DACITES

The dacites may be thought of simply as andesites with quartz. They are not common in the Philippines. I have seen only two good specimens; one from Benguet and one from Corregidor Island. Field and petrographic descriptions of this rock are given by Becker(50) and by Iddings.(337) One specimen from Antamok, described by me as follows, is interesting:

BENGUET NO. 116.—DACITE

Macroscopic.—A hypocrystalline, rather aphanitic rock, which has a somewhat porphyritic fabric and is greenish yellow. The rock has a dense, bluish, fine-grained groundmass in which are numerous phenocrysts of epidote, themselves not large, rounded areas which appear to be decomposed feldspar and occasional, clear, limpid, more or less rounded or irregular, areas of quartz. There are very few ferromagnesian minerals visible in the hand specimen, and they are mere black specks.

Microscopic.—The prominent features of the slide are:

1. The saussuritized feldspar (plagioclase) phenocrysts.
2. The comparatively clear, rounded phenocrysts of quartz.
3. The groundmass in places quite trachytic, in others glassy, the whole having a felty or hyalopilitic character.

SECOND GROUP OF IGNEOUS ROCKS

The rocks of the second group, in the order of their apparent abundance, are the following: Quartz-diorite, diorite, gabbro, metadiorite, peridotite, granite, syenite, and pyroxenite. This statement is based upon the number of occurrences in the Bu-

reau of Science collection of petrographic slides which were all determined by Iddings. This, of course, is an approximation only.

DIORITE, QUARTZ DIORITE, AND DIORITE PORPHYRY

The parent magma of the Philippines was of such composition that the part which reached the surface produced an andesite or dacite; the portion which did not reach the surface cooled more slowly and became diorite, or quartz diorite, or diorite porphyry. Therefore, we would expect to find these holocrystalline rocks in the deeper stream cuttings.

The chief characteristics of the diorites are the considerable amount of hornblende and that the feldspar is principally plagioclase. When they contain quartz they become quartz diorites, and on the other end they merge into the gabbros.

Quartz diorites have been found in Benguet, Tayabas, and the Camarines region. Of the Benguet rock (Antamok) Iddings says:

* * * is medium-grained quartz-diorite with inequigranular consertal [grown together] fabric. It consists of plagioclase and considerable brownish-green hornblende, anhedral [without good faces] with respect to each other, but euhedral [with good faces] toward quartz and orthoclase. There is some altered biotite. In places the orthoclase is intersertal [intergrown] to poikilitic with inclusions of plagioclase and hornblende.

I give here an early description of my own of a specimen from the same locality and my calculation of it according to the quantitative system.*

BENGUET NO. 12.—QUARTZ DIORITE [BATWAAN]

This is a section of a typical quartz diorite. It is quite fresh, showing little or no alteration. The texture is granitic, holocrystalline, fabric *hypidiomorphic-granular* [crystal not perfectly shaped]. The minerals of the rock are plagioclase and orthoclase feldspar, hornblende (actinolite) quartz, magnetite, and accessory apatite. The feldspars for the most part are plagioclase, exhibiting both Carlsbad and albite twinning. From the extinction angles which were taken on a section cut normal to the albite twinning I made out this piece at least to belong somewhere near the middle of the series, oligoclase or labradorite. Some orthoclase is present, associated more or less with the quartz. It is decidedly not the dominant feldspar. The amphibole is the pleochroic, grass-green variety known as actinolite with pleochroism as follows: b = colorless to yellow; c = dark green. Quartz occurs wholly as interstitial material. Magnetite is found as minute, rounded grains inclosed by hornblende.

* Washington, Iddings, Pirsson, and Cross, Quantitative Classification of Igneous Rocks (1903).

A series of measurements on this slide established the following approximate proportions of the various minerals, from which was calculated the following analysis:

Constituent.	Per cent.
Quartz	2.94
Plagioclase	67.09
Hornblende	22.93
Magnetite	6.28
Olivine	.73

Accessory minerals an [are] almost entirely lacking, or so inconspicuous as to warrant no lengthy search for them.

Constituent.	Calculated from mineral contents. Per cent.	Calculated by chemical analysis. Per cent.
SiO_2	56.89	57.06
FeO, Fe_2O_3	8.58	6.04
Al_2O_3	17.52	20.00
MgO	2.9	3.27
Na_2O	7.32	2.95
CaO	3.97	7.18
H_2O		3.06
	97.18	100.00

Remarks.—A greater number of measurements would doubtless raise the silica content by showing more quartz. In this calculation the orthoclase was taken with the plagioclase. This, in close work, strictly should not be done. Making allowance for orthoclase we should have a lower Na_2O figure and about 3 per cent of K_2O.

Examination of additional sections of this rock revealed some small amount of biotite.

By calculation I have placed this rock as follows in the quantitative classification: Class II, dosalane; subclass I, dosalone; order 5, germanare; rang 3, andase; subrang 3, shoshonose.

Other quartz diorites have been encountered in Batangas Province (Lobo Mountains), on Masbate Island, in Lepanto Subprovince, and elsewhere.

The extensive and rich mineralization of Antamok Valley, Benguet, is due, in the opinion of many, to the quartz diorite intrusive in that region. Plate 4, fig. 2, shows a characteristic diorite from Baguio.

Diorites occur in Batangas, Benguet, the Camarines region, and several other localities where there is a true cordillera. Diorite appears to be the typical basal complex rock in Cebu, my description of which, published some years ago, follows.(561)

For some time I was puzzled by the particular phase of igneous rock constituting the hills on the left, or north side, of the Danao River. Here the rock is more of a porphyry than holocrystalline * * * A feature of this rock is the innumerable, minute, calcite veins cutting through it without definite system.

The following is a description of this rock from the region of Sili Creek [Cebu], not far from the coal measures.

CEBU NO. 5 (DILWORTH).—DIORITE PORPHYRY [DANAO RIVER]

Hand specimen.—A dark colored, fine-grained, igneous rock. The only minerals identifiable in the hand specimen are dark green plagioclase and rare specks of magnetite.

Microscopic (2 sections).—The rock is composed almost entirely of feldspar, rather decomposed. There are several porphyritic crystals reaching a maximum size of 2 by 1 millimeters, but the majority are small laths. About 5 per cent of the feldspars seem to be orthoclase. No good determinations could be made of the plagioclases, but six rather doubtful ones gave three of acid labradorite and three of basic oligoclase. Many of the feldspars show good zonal structure. Several, especially among the smaller laths, are bent.

Biotite is present in all stages of decomposition, but is always well chloritized. There are no well-defined plates.

Quartz occurs in small and inconspicuous grains. It forms a very small part of the rock and is accessory rather than essential.

There are a large number of small crystals of titaniferous magnetite or limonite, generally associated with the biotite. The presence of titanium is shown by the dirty white titanite, which surrounds these crystals.

Secondary minerals are: Kaolin and sericite, along cracks in the feldspars; chlorite replacing biotite; patches of calcite; and titanite associated with the magnetite.

METADIORITES

The metadiorites include a number of rocks in which the hornblendes are not primary but secondary. They are derived from holocrystalline rocks containing pyroxene.

GABBROS

These rocks may be thought of as having cooled too slowly to form basalts. They stand in the same relation to basalts as do diorites to andesites. It is important to understand clearly the generic relationship of the coarser rocks and the extrusive lavas in this region. The important feature of the quantitative classification is that the norms of a basalt and a gabbro are not essentially different, and the same is true of andesites and diorites. The older classifications did not show this.

As would be expected from the prevalence of basalts in the Archipelago, gabbros are very common. An olivine-gabbro from river gravel at Montalban, Luzon, contains labradorite (Ab_2An_3), pale green augite, colorless olivine, and very small

amounts of secondary hornblende, biotite, and magnetite. There also are some secondary minerals locally developed, such as chlorite, serpentine, etc.

A very fine-grained norite is found in Palawan.

Gabbros with an ophitic texture, that is, with the component minerals forming a latticelike structure, often called diabase or dolerite, are numerous.

PERIDOTITE

When a gabbro contains much olivine it is customary to call it a peridotite. While this rock is not common in the Islands, there are several occurrences of it. It is found in the Camarines region and in the Cinco Picos Range, western Luzon.

PYROXENITE AND PERIDOTITES

Bare brownish and rocky hills, having scattered white patches of efflorescence, occur in many parts of the Islands. Such hills usually are composed of pyroxenite, passing in places to peridotite, and where altered this yields a serpentine. The efflorescence is magnesite (magnesium carbonate) derived from the decomposition of ferromagnesian minerals in the rocks. This rock is almost black, inclined to greenish where passing into serpentine, and is very hard and dense. I have noted great areas of this formation in the Camarines region, Batan Island, Albay, and Ilocos Norte. There is usually an accumulation of lateritic iron ore associated with this rock. These basic rocks are very important as being the source of chromite, magnesite, platinum, and nickel, nearly all of which important economic minerals have been found in small quantities in the Philippines. Abella's description of a closely related rock called picrite is taken from his Panay work.(12)

> The *picrites* have a beautiful emerald-green color with bronze metallic reflections of a crystalline texture, and in them are seen olivine, augite, and bronze hypersthene, a white mass being distinguished among these crystals, semigranular, almost pulverulent, which at some time might have originated from a pre-existent feldspar or nepheline, which cannot now be classified as such. Under the microscope this white mass resolves itself into a whitish magma, amorphous and decomposed, which in the polarized light emits, notwithstanding, certain pale gray-bluish and yellowish colorizations, all of which confirms the supposition of feldspathic and nephelenic origin, not explaining satisfactorily however, such complete decomposition of the white element only.
>
> Based on these characters and on the texture almost holocrystalline which the three elements of this rock affect, we shall classify it as peridotic, designated with the name of picrite.

GRANITE

True granite is a rather rare rock in the Philippines. So far as I know, the best development of granite in the Islands is in the Paracale-Mambulao mining district, Camarines Norte. It has been so squeezed during the regional metamorphism of the district that it now has a gneissoid structure.

Iddings, who visited the district with me, says the granite of Mambulao has been sheared to a thinly laminated gneiss with "Augen" structure on a small scale. The orthoclase and albite lie as anhedral blocks in a matrix of smaller equant anhedrous (shapeless) quartz and orthoclase with shreds of muscovite (and chlorite, it should be added) having pronounced fluxion structure. There is an extensive development of granite which cuts the quartz diorite of the Baguio district on the east and appears to continue northward, at least as far as Bontoc. These "granites" probably conform more nearly to the composition of grano-diorite than to the true biotite-orthoclase-quartz rock. Rocks of the grano-diorite type make up a goodly portion of the Cordillera Central of Luzon and are found in several other islands as well. According to Iddings's list, made from the collection when it was smaller than now, the only grano-diorite he notes are the specimens collected by me in Batangas. Nevertheless, it would seem that it were better to use grano-diorite to cover all the granitoid rocks intermediate between granite and diorite. For the purposes of this study these refinements between quartz-monzonite, grano-diorite, and quartz-diorite are not necessary.

SYENITE

A sodic syenite has been found in Masbate. I have seen nothing else that in character even approaches this rock. In concluding his paper Iddings says:

> * * * The extremes of the mineral variation, or differentiation in this region appear to be albitic granite and albitic syenite on the one hand, and peridotite and possibly pyroxenite on the other. * * *
>
> There are not sufficient data at hand to determine the relative abundance of the different magmas and so indicate the composition of the average or "parent" magma. It appears that the coarser-grained, intrusive rocks have attained a higher degree of differentiation than the extrusive lavas, but this may not be the actual fact, and further study of the region may modify this conclusion.

THE CLASTIC ROCKS

The petrography of the fragmental or clastic rocks in the Philippines has been comparatively neglected. In the Bureau

of Science is a fair collection of thin sections, representative of the dominant sedimentary rocks throughout the Archipelago. Nearly every variety of clastic rock known is represented here. The principal clastic rocks of the Philippine Islands are of the following types: Arkose, sandstones, tuffs, shales, limestones, conglomerates, and cherts. Of these the arkosic sandstones and tuffs seem to be the most abundant. There is nothing in the Philippines comparable to the clean quartz sandstones in the United States; in fact, all the sandstones show subangular grains of more or less heterogeneous material, some quartz, more lime-soda feldspars, ferromagnesian minerals, and magnetite. They are derived from the breaking up of basic igneous rocks, andesites, diorites, and gabbros largely.

ARKOSE

An arkose from Cebu collected by me was described by Ferguson as follows:(561)

CEBU NO. 45.—ARKOSE [COT-COT RIVER]

Hand specimen.—Extremely fine grained, grayish rock, the distinguishable minerals of which are pink feldspars, quartz, magnetite and occasional hornblende (?). The grains are all very small and approximately the same size.

Microscopic.—The rock is much decomposed, especially the feldspars. Feldspar is the most prominent mineral, and is chiefly orthoclase, but one grain of albite was found. There are no perfect crystals, but occasional crystal faces occur. Quartz is rather rare in definite grains, but seems to fill spaces between other crystals. Biotite occurs in small amounts, but in bent and frayed fragments rather than plates. Occasional fragments of hornblende crystals are present. Magnetite occurs in numerous, small grains, often partly altered to limonite. One grain of topaz (?), a few minute grains of olivine (?) and numerous very minute grains (diameter generally about 0.01 millimeter) of a mineral with high refractive index and rather high double refraction, apparently titanite, are the accessory minerals.

The rock shows no definite structure. The grains vary in size, but never exceed 0.25 millimeter and perfect crystals are never found. The biotite especially presents a fragmental appearance. I believe the rock to be an arkose, formed by the decay of a trachytic igneous rock and with only slight transportation, as there is no evidence of assortment of the minerals.

I have recently studied a number of thin sections of clastic rocks collected by H. G. Schenck in Samar, and most of them proved to be arkosic sandstones. As in Samar, throughout the Philippines there are few occurrences of true sandstone with rounded quartz grains as the chief mineral, but these impure sandstones, somewhat gritty, rather more like arkose, wackes, etc., abound.

SANDSTONES

As the Canguinsa sandstone in the upper part of the Vigo group is perhaps the most prominent sandstone in the Archipelago, this being the one generally overlying the Miocene coal, I give here a short description of this rock. Owing to the exceedingly friable nature of practically all Philippine sandstones, it has been impracticable to make slides for microscopic examination, but I have been able to study the mineral components by digesting the rock with hydrochloric acid and placing the loose grains under the microscope. A typical specimen so examined, collected on Bahay River, Bondoc Peninsula, Luzon, by W. E. Pratt, showed generally well-rounded to subangular grains, usually under a millimeter in diameter, of quartz, feldspar in small quantities, olivine, hornblende or pyroxene, and magnetite as the dominant constituents. These grains were held together by calcium carbonate and some iron oxide. With the acid there was strong effervescence and immediate and complete disintegration of the rock. There is complete gradation from these sandstones to the exceedingly fine-grained shales.

A sample of the Cudiapi sandstone from the Malumbang (Pliocene) is more indurated and somewhat finer grained. However, on treatment it showed an even greater percentage of lime than the other sandstone. The insoluble ingredients are, if anything, more angular and, perhaps, contain more quartz than any other mineral. The ferromagnesian minerals and magnetite were much fewer.

A TYPICAL TUFF

The greatest area of tuff is that in the vicinity of Manila, extending both southwestward and northward along both the eastern and western sides of the great central plain of Luzon. This material is used for construction in Manila. Cox made an investigation of it as a possible cement material, and during this work made the following microscopic notes:(157)

> A microscopic examination of the tuff in the vicinity of Manila shows it to be composed of (1) plagioclase, both decomposed and undecomposed. There seem to be two generations of feldspar; the one rounded and largely decomposed, the other rather angular and in appearance as if it had come from a greater distance, (2) magnetite, (3) hornblende, (4) quartz grains, (5) the cementing material, which is probably in greater part volcanic ash, is largely composed of oxide of iron. It might also be mentioned that a certain amount of pumice is nearly always to be found in this tuff. It is undoubtedly andesitic tuff.

LIMESTONES

Descriptions of two limestones differing very markedly are added. These are from studies(560) made by me some years ago on material that I collected in Benguet.

BENGUET NO. 108.—FORAMINIFERAL LIMESTONE

[Naguilian Road]

Macroscopic.—This is an aphanitic, pink-colored rock with conchoidal to hackly fracture, it contains a few veinlets filled with rusty calcite. The rock on its weathered surface has a dirty, bluish-gray appearance. It effervesces strongly with acids.

Microscopic.—Under the microscope the rock is seen to consist chiefly of large and small grains of calcite with almost every conceivable shape, stained copiously with iron oxide, which of course gives it its red color. The rock also contains the remains of the two well known Miocene fossils, *Operculina complanata* Bast. and *Lithothamnium ramosissimum* Reuss.

Remarks.—I have found these same forms in limestones from Cebu Island, Polillo Island, [Benguet], Lepanto Province, Luzon, and other localities.

LIMESTONE FROM THE BENGUET ROAD

[Foot of the Zigzag]

Macroscopic.—In the hand specimen this rock is quite black, in portions very fine-grained, in others crystalline; it is occasionally streaked with minute calcite veins. It is very fossiliferous, but as the rock is very hard it is difficult to remove the fossils, which are for the most part large bivalves.

Microscopic.—The dark color is due to an excessive amount of iron oxide in the matrix. Large amounts of calcite in more or less rounded grains are to be seen in the slide, these practically make up the entire rock. Fragments of foraminifera are quite abundant, but, owing to their state of preservation we can make little more than a guess as to their identity. Some of these very much resemble sections of *Operculina* and there is another section which suggests a nummulite as it possesses "alar prolongations" between the successive whorls.

An interesting limestone conglomerate from Samar is shown on Plate 7, fig. 2, made from a specimen collected by H. G. Schenck.

CHERTS

In the chapter on Stratigraphy are included some descriptions of the radiolarian cherts of the Ilocos Norte country. The rock is a hard jaspery material, reddish and very fissile. The field relations are obscure. The petrographic description is given in the chapter on Stratigraphy.

THE METAMORPHIC ROCKS

Metamorphic rocks in the Philippines are especially abundant in Ilocos Norte, Bulacan, and the Camarines region in Luzon, in

northern and eastern Mindanao, especially in the Surigao region, in Palawan, etc.

The commonest metamorphic rocks are the schists; next come the serpentines; third, "slates;" and fourth, marble. Gneisses also are metamorphic. Some of these are due to local, but chiefly to regional, movements attendant upon the various elevations and submergences of the Archipelago.

As I am practically the only one who has done petrographic work on the schists of the Philippines, and as the schists of the Ilocos Norte country are typical, I quote from my published notes on them.(558)

At Dalumat I found magnetite, talc, mica (several species), actinolite and chlorite schists, all in a very much disturbed and mixed condition, but in this region the mica and talc schists prevail; farther to the north near Dungon-Dungon, magnetite schists are better developed, and there is also a very feeble development of eclogite. I found, from my study of schists and eclogites from the Coast Ranges of California, that the metamorphism of sedimentary rocks usually produced gneisses and schists, whereas the eclogites could in some cases at least be traced back to an igneous antecedent. However, in the Ilocos Norte region I have not in mind a single instance where I could actually trace these transformations in the field. This much, and only this, we can be sure of at the present time; that is, that the mica and talc schists are found between the granite (f. n.) intrusive mass and the later sediments; the magnetite schists and eclogites are more intimately associated in the field with the basal igneous mass, usually near its edges.

MINERALS OF THE SCHISTS.

Actinolite schists.—These are to be found in patches everywhere bordering the serpentine area. Some of the rocks are entirely made up of long actinolite crystals, while in others actinolite is only one of the several constituents. Slides from two different rocks from near Pine View Point were examined. The first one consists largely of a mass of actinolite fragments with interstitial, more or less rounded feldspar grains, rarely showing polysynthetic twinning, the whole complex with every appearance of having been derived from a sediment; extreme granulation is a feature of this rock. The second one is made up almost entirely of actinolite with probably some interstitial chlorite. In parallel, polarized light the actinolite shows marked dichroism. a = colorless, c = olive green. The actinolite does not occur in whole, unbroken crystal sections, but is in a very much frayed state, in fibers which are the result of breaking along the cleavage lines parallel to c.

Mica and micaceous schists.—Nearly every species of mica known to mineralogy can be found, it seems, in the schistose areas near Pasuquin, [Ilocos Norte, Luzon]. These minerals all occur in small pieces, seldom as complete crystals, they occur very irregularly along shearing planes. The lighter micas such as muscovite, paragonite, etc., and micaceous talc seem to predominate. * * *

Extensive development of mica schists occurs in this region, paragonite and margarite being the predominant micas.

Scales of this white mica, when viewed in a petrographic microscope, show a fine interference figure with an axial angle of 37°. A qualitative analysis demonstrates the presence of sodium and calcium, so that we probably have both paragonite, the sodium variety, and margarite, the calcium mica.

Magnetite schist.—Many outcrops of schists occur in the vicinity of the Baruyen River and magnetite schist, in which the magnetite cubes and octahedra attain a diameter of 10 millimeters or more, is found among these.

Epidote-magnetite schist.—This rock, in thin section, consists largely of a felty mass of actinolite and chlorite with phenocrysts of magnetite and epidote. The magnetite occurs in diamond and octagonal sections, also in rounded and irregular grains; the epidote, in idiomorphic crystal sections is on the average 0.67 by 0.08 millimeter. These epidotes are distinguished by high relief, parallel extinction and the characteristic, irregular fracture. The difference in absorption along the a and b axes is as follows: a = colorless, b = straw yellow.

I have studied all the specimens of schists collected by the other members of the division of mines staff, principally those of Pratt from Caramoan Peninsula, Camarines Sur, Luzon, but have seen nothing essentially different from those mentioned above. One important conclusion concerning those from Caramoan, made by Pratt,(497) which checks earlier statements made by me,(580) is as follows:

The metamorphic sedimentaries exhibit a succession of beds identical in its main features with the Philippine column of Tertiary sedimentaries. The observed sections in the metamorphosed sedimentaries and in the unchanged sedimentaries farther east are similar, although the lower part of the metamorphosed section is developed in greater thickness than the corresponding division of the unchanged rocks. Moreover, in ascending Caramoan River, one passes gradually from unchanged sedimentaries to metamorphosed sedimentaries: that is to say, there is an evident transition from one formation to the other with no definite line of contact.

In short, the schists and marbles appear to be no older than the shales and limestones. Indeed these rocks appear to be different sections of continuous beds which have been metamorphosed in their westward extension but have escaped metamorphism farther east.

Thus the schists and marbles are likewise not older than the Oligocene, and the antiquity which has been ascribed to the metamorphic rocks generally in the Philippines is opened to question. Paleozoic schists are found in Japan and in Formosa, and they may exist in the Philippines, but the extensive area of more or less typical schists on Caramoan Peninsula belongs to a later period.

SERPENTINE

Serpentinization is common in many parts of the Philippines. One of the first rocks studied by me and described in 1905 was a

serpentine (Plate 6, fig. 2) on Batan Island, Albay Province, Luzon.(554) The original description follows.

Megascopic.—In the field this rock is seen to grade from a fine-grained dark-green, almost black, basalt (f. n., field and quantitative classification of igneous rocks) to a porphyritic rock with large pyroxene crystals over an inch in length, and from this to a true serpentine. Specimens are at hand which show the merest remnants of the original rock included in a network of greenish serpentine and white magnesite. The serpentine and magnesite are only found on weathered faces such as along the seaward cliffs of the long bare ridge running from Calanaga Bay to East Point.

In the vicinity of Liguan and Caracaran only the fine-grained aphanitic facies was seen.

As one skirts along this great ridge of serpentinized rock he is struck with its likeness to similar rocks along the California coast.

Microscopic.—When studied microscopically the rock is seen to be not a basalt in the commonly accepted meaning of the word, as the feldspars are characteristically lacking. In the less-altered sections the chief minerals were found to be olivine, a pyroxene or amphibole (not readily distinguished from the alterations), and magnetite. The whole section is seen to be a network of serpentine even though the hand specimen does not show it.

This rock was called a basalt by Lieutenant Markham, but that identification was made simply from a hand specimen hastily examined in the field. The rock is more of a peridotite than anything else, though it grades into a pyroxenite. The writer has examined microscopically identical rocks from the Coast Range of California.

MARBLE

Marble is widespread though not developed over great tracts. The best-known deposits are on Romblon Island. As this rock is not essentially different from similar rocks elsewhere I shall omit the petrographic description.

"OLD SLATES"

These are generally associated with the schists in certain portions of the Archipelago and have been discussed rather fully in the chapter on Stratigraphy. As these, owing to the fineness of grain, do not readily lend themselves to petrographic examination, I shall not attempt a further description of them.

SUMMARY AND CONCLUSIONS

Iddings says:(338)

In the Philippine Islands the igneous rocks appear to be very similar to those in Japan, but very few have been analyzed chemically. The lavas are chiefly andesitic, with less basalt and very little rhyolite. The plagioclase of the andesites is noticeably calcic, many phenocrysts being labradorite. The rocks are chiefly dosodic (dominantly sodic).

In Masbate more potassic varieties occur near Aroroy, some aphanites containing altered leucite.

Long ago Becker wrote:(50)

The basalts and andesites of our Asiatic province might have come from Alaska or from the western Cordilleras of North America, so far as their composition and structure are concerned. There is the same unexplained adherence of the feldspars to definite types, only emphasized by cases of exceptional composition. There is the same general uniformity in the groundmass of the rocks, accompanied by the occurrence of numerous exceptional microlites and not very infrequent reversals of the ordinary rule of deposition, according to which the more calcic feldspars are precipitated before the more sodic species.

Farther on he refers to the relationships between the rocks of the Philippines and those of the rest of Malaysia, as follows:

The volcanic rocks of the Sunda Islands and the Banda Islands are seemingly in all respects similar to those of the Philippines. In the Dutch and English possessions in the Far East there is the same preponderance of pyroxene-andesite accompanied by hornblende-andesites and basalts. Leucite rocks, rare in Asia, occur on the small Island of Bawean, to the south of Borneo, and in eastern Java, as well as in Panay, and dacite accompanies andesites in the islands of the Uliasser group, while trachyte seems to be rare. The similarity extends beyond specific names. Mr. Oebbeke made direct comparisons between the Semper collection and the specimens in Professor Rosenbusch's cabinet from other parts of Malaysia. He concludes that "there is scarcely a type which is not represented on all the islands alike."

Table 6 shows chemical analyses of typical Philippine rocks, made by various chemists of the Bureau of Science.

TABLE 6.—*Analyses of Philippine rocks.*

Constituent.	Ilocos Norte granulite.	Benguet quartz-diorite.	Mankayan diorite.	Basilan gabbro.	Ilocos Norte pyroxenite.	Benguet andesite.	Cebu rhyolite.	Romblon schist.	Romblon marble.	Cebu sandstone.	Batan Island shale; depth 114 m.	Benguet limestone; 1,500 m. elev.	Cebu limestone; near sea level.	Guadalupe (Manila) tuff.	Cebu marl.
Silica (SiO_2)	72.56	57.06	50.67	52 47	37.58	53.92	67.25	80.12	0 10	72 76	34 80	1 90	8 37	56 55	44 35
Alumina (Al_2O_3)	15.13	20.00	21 21	17.16	0.57	18.68	13.12	12.56	0 17	15 58	11.70	1.72	0 22	22 34	20 26
Ferric oxide (Fe_2O_3)	2 54	6.04	11 31	1.89	9.49	4 27	0.24	1 15		1 42	2 69	0 30	3 25	1 87	4 64
Ferrous oxide (FeO)			0 21	8 08		2.65					3.47	0.04			
Calcium oxide (CaO)	2 01	7.18	6 86	9 21	0 48	8 85	1.23	0.12	55 23	0.62	17.19	52.11	49.84	4.74	11.37
Magnesium oxide (MgO)	0.95	3 27	4 10	5 32	32 34	2.93	1.10	0.48	0 45	Trace.	2.84	0.97	1 02	2.36	2.59
Sodium oxide (Na_2O)	5.06	2.95	1.41	0 82	0 32	2 92	0.59	3 69			1.46	0 20		2 38	
Potassium oxide (K_2O)	0 56	3.06	0 10	0.36	0 20	2 66	4 38				0.80	0.07		2.84	
Loss on ignition	[a] 0 03		[a] 2.74	0.80	6.70	[a] 2.23	6 11	2 14	43 80	3 53	17.19	[a] 42.49		4.86	14.30
Moisture	[a] 0.93		[a] 0.50	[a] 1.59	[a] 12 64	[a] 0.44	[a] 6 15			[a] 1.84	[a] 4.90	[a] 0 16		[a] 2 51	
Titanium oxide (TiO_2)	Trace.			1 53	Trace.						0.95				
Sulphuric anhydride (SO_3).											None.				
Sulphur (S)				Trace.							0.61				
Manganese oxide (MnO)	0.46			0.36	0 28						0.09				
Phosphorus pentoxide (P_2O_5).	None			Trace.	None.										
Chlorides (Cl)				Trace.											
Total	99.27	99 56	99.11	99 59	100 60	99 55	100.17	100.26	99.75	95.75	98.69	99.96		100.45	97.51

[a] At 105°

GEOLOGIC HISTORY

Becker,(50) in an admirable summary of the geology of the Philippines as known in 1901, gives a short outline of the geologic history of the Archipelago; later work has clearly shown that this must be substantially modified. In the first place, he says:

> It would seem that * * * from early Paleozoic times onward an archipelago has usually marked the position of these islands. Prior to the Eocene nothing definite is known of them, but further investigation will very likely disclose Paleozoic and Mesozoic strata there * * *.

I know of nothing to indicate the existence of any land mass in Paleozoic times on the site of the present Archipelago. Various geologists have tried to prove the existence of Paleozoic formations by the presence of gneisses and schists, without a shred of evidence other than that they look old and because many such rocks are found in the older formations of other countries. Therefore, they argue, Paleozoic formations must exist here. This is faulty reasoning. As a matter of fact, there are here schists and slates which may be Paleozoic, and which are unconformably below the Tertiary sediments; presumably, these are Mesozoic in age, but we do not know this certainly. On the other hand, there are some schists in the Philippines that appear to be nothing more than metamorphosed Tertiary shales and sandstones.

It is reasonably certain that during Mesozoic time there was some land mass to represent the Philippine Islands, since below the Tertiary are the materials mentioned, and they must have been derived from materials that came from a neighboring land mass and, later, were metamorphosed into slates and schists. There were also other deposits, radiolarian cherts, possibly of deep-water origin, which have been correlated with Bornean equivalents and also with the Franciscan (Jurassic) of California and Oregon. Interbedded with the slates, in which no fossils have been found, are lenses of manganese oxide which, to some, point clearly to deep-sea origin. With these also should be grouped the grano-diorite, the diorite, and the granitic intrusions found in various parts of the Archipelago, especially in Luzon. These rocks were intruded into the existing rocks probably late

in the Mesozoic, since their equivalents in other countries about the Pacific are post-Jurassic. Some gold and copper ores are associated with these post-Jurassic (?) batholiths, as on much of the Pacific border; they mark the first period of ore deposition in the Archipelago.

At the close of the Mesozoic (during the Cretaceous period, probably) there was intense dynamism with perhaps both subsidence and uplift; this was the time of the formation of the slates and schists. Similar rocks are found in Borneo and Java where they are known as "old slates" and "old schists."

Apparently, there is no Cretaceous in the Philippines; at least, none has been identified. Probably at that time the Philippine Archipelago was a great land area above the sea.

Previous to this there may have been land connection between Luzon and Formosa. Whether that connection was broken in pre-Tertiary or in Tertiary times I am not prepared to say. Connections with Borneo and Celebes probably continued until a much later date.

When we come to the Eocene it must be confessed that it is somewhat puzzling to try to outline the sequence of events. Although there are coal seams and accompanying formations closely simulating those of the Eocene of Java, the fossil evidence indicates that Philippine coal is Miocene. Between the older slates, schists, and cherts and the coal series is a great basal conglomerate, possibly represented by the Agno beds of Luzon, which indicates an unconformity and a long period of erosion, probably during the Eocene; that is to say, during the Eocene most of the Archipelago stood out of the sea.

Following the Eocene, during the Miocene, was a general subsidence and a great period of deposition in shallow water, during which the coal deposits were laid down. Even at that time there were isolated masses of older and more-resistant rocks represented by the cores of many of the islands of to-day. Where northern Luzon is now there was at that time a land mass much larger than any other within the confines of the Archipelago, and at this time masses like the present islands Luzon and Mindanao were separated into several smaller islands.

Beginning early in the Miocene, but more pronounced after the middle and continuing until the close of that period, there was a general emergence accompanied by folding of the sandstones and shales and coal beds previously deposited. This was the well-known "Miocene Revolution" of almost worldwide extent.

At the same time much faulting occurred, and several separate blocks, having the general positions of the present large islands, were produced.

As a concomitant of this folding and faulting there were intrusion and extrusion of andesitic and basaltic lavas, followed by ore deposition, marking a second epoch of this kind in the history of the Archipelago. Ore deposition may be occurring at the present time, as recent spring deposits of a siliceous sinter near Baguio show an appreciable amount of gold.

Succeeding these events there ensued a period of erosion and another subsidence when the Malumbang sandstone and limestone series was laid down as a veneer overlying and unconformable upon the older Vigo and Batan series of the Miocene. During this time the waters were still shallow, and coarse sediments and reef limestones were formed.

Finally, another period of uplift began, which, undoubtedly, with interruptions marked by local subsidence, proceeded into the Pleistocene. This elevation is one of the major episodes in the geologic history of the Archipelago. It is attested by the presence, at about 1,500 meters elevation in north-central Luzon, of a fossil flora very similar to that now growing in the lowlands near Manila.

In two or three small areas of northern Luzon we find plateau-like topography to-day, notably around Baguio. These areas have some of the features of peneplains which might be explained as having been formed when the Archipelago was relatively low lying just preceding the last uplift and are now isolated as fault blocks. This is one theory. I do not believe that it is necessary to stipulate complete base-leveling; they may have been formed at high elevations. However they may be explained, they probably date from the Pliocene.

Within Recent time differential movements, submergences, and elevations have undoubtedly taken place, in some parts indicated by drowned rivers, in others by moderately elevated beaches and reefs. The last episodes in the history of this Archipelago have been the building up by explosive action of volcanic cones of fragmental ejecta, such as those of Mayon, Arayat, and Taal; the work of degradation by the streams; reef building, etc.

From the present rate of erosion, deposition, and diastrophism observed in Malaysia I am inclined to believe that the geologic age of the Philippine Archipelago is not so great as some geologists have estimated it to be. I will hazard no guess as to the

actual age of the Philippine Islands in years, because it appears at first sight to be a matter of no importance and there are insufficient data upon which to base an estimate.

According to Prof. H. O. Beyer, many of the areas of the Archipelago may have become isolated and separated from other Malay land areas since the Negrito became distributed; therefore, for a subject of this kind, the matter of age is vital. For many reasons I have given here an outline merely of the major events in the geologic history of the Philippine Archipelago; the details cannot yet be supplied. Many interesting facts relating to the distribution of the present plants and animals, including man, can be interpreted only upon the basis of this history and the paleogeography of the group and the ancient land bridges connecting the Philippines with Borneo, Celebes, New Guinea, and other land masses. Enough has been done to show that the peculiar facts in this distribution can be explained by the isolation of blocks of the Philippine terrane through the breaking of these bridges. The dates of some of these events can also be stated with a fair degree of probability.

REGIONAL GEOLOGY *

LUZON

Luzon is the largest island of the Philippine group. Geologically, it is worthy of constant study as it is a link in the great "Circle of Fire" that girds the Pacific. From it, doubtless, are to be wrested important secrets relating to such questions as the former configuration of Asia, past climatic changes, and possibly something of the early history of man. The dominant features of Luzon are the long coast line, its many fine harbors, the mountainous character of much of its interior, its great central plain, and its beautiful volcanic mountains. It is a region of tremendous rainfall (115 centimeters in twenty-four hours, recorded by the Government Observatory, Baguio, in July, 1911) and is in the track of the most frequent and violent typhoons. The island is situated between 12° 30′ and 18° 40′ north latitude and has much high country which is also fairly rich in minerals. For these reasons it attracts men interested in mining. There is abundant evidence indicating that Luzon will before many years have a prominent place as a mining field. The richest gold mine in the Far East is situated on this island.

PHYSIOGRAPHY AND GEOLOGY

The chief physiographic units from west to east, indicated by Adams,(21) are as follows: The western or Zambales cordillera; the great central plain; the Ilocos coast strip; the Cordillera Central; the Cagayan Valley; the northeast cordillera, or Sierra Madre Range; the southwest volcanic region, with Taal as a center; the eastern cordillera; the southeast, or Caramoan cordillera; the southeast volcanic region, with Mount Mayon as a center; and the "Central Knot," which is merely an elevated region where several of these units merge.

The most extensive discussions of the geology of Luzon are those published by von Drasche,(200) Eveland,(237) Adams,(21) and Smith.(589)

* This is a greatly revised summary of some of my articles that have been published in the Philippine Journal of Science, the Journal of Geology, and other periodicals.

HYDROGRAPHY

Space does not permit of a lengthy description of the hydrography of Luzon, but a few of the most important rivers and lakes should be discussed in this place rather than under the respective physiographic districts, since several of the rivers traverse more than one of these. The longest river is the Cagayan, in the northern part of the island; the shortest, perhaps, is the Pasig, but from a human standpoint, the Pasig is by far the most important of all. The following are the nine principal rivers of Luzon:

RIVERS

Cagayan River.—Cagayan River is about 300 kilometers long, flows almost due north, save for its meanderings, and drains the extensive Cagayan Valley of northeastern Luzon, the great tobacco district of the Archipelago. It is navigable for ocean-going vessels of light draught as far as the town of Tuguegarao, about 100 kilometers, and for boats drawing not over a meter as far as Echague, 200 kilometers. This river has two large tributaries, the Chico and the Magat, and with these it drains practically the whole of northeastern Luzon.

Pampanga River.—Pampanga River rises in the "Central Knot" of the mountains of Luzon, the Caraballo Sur, and flows down the eastern margin of the central plain, very close to the eastern cordillera, and thence slightly west of south to Manila Bay. Its lower end breaks up into a network of canals, which anastomose with those of one or two smaller streams that flow from the center and the western margin of the southern half of the central plain. In its lower portion it is a fine example of a "braided" stream. It is navigable for steamers of light draught as far as Mount Arayat, a distance of about 100 kilometers, and for rafts as far as Cabanatuan, about 200 kilometers. Most of this river is wide and shallow, with low mud banks. Just east of the river and parallel to it is the long and narrow Candaba Swamp, whose size changes with the seasons.

Agno River.—Agno River rises on the flanks of Mount Data, but flows south in another structural valley and debouches onto the central plain of Luzon. Due to possible warping of this plain, or merely to irregular deposition, the river makes a great sweep and turns northwest, emptying into Lingayen Gulf by way of a series of smaller channels. It is practically entirely unnavigable, but is worthy of consideration because of the great

destruction caused when it overflows its banks as happened very disastrously in the rainy season of 1911. At that time almost the entire country from Moncada to Dagupan was under water, and in places the flood rose nearly to the tops of the telegraph poles. At the same time an important new dam and irrigation project which the Government was building was almost completely obliterated.

Abra River.—Abra River rises on the flanks of Mount Data, in north-central Luzon, and flows west for a short distance before it turns northward—in the tectonic valley east of and parallel to the Malaya Range—almost as far as the town of Dolores, where it turns sharply west. From this point it proceeds in a south-of-west direction and breaks through the coast range south of Vigan. It is navigable only for rafts and dugouts. From the situation of this stream and some of its tributaries, it is my opinion that the Abra is a captured stream, and that formerly there was a more important water course of greater length which followed Abra Valley, though possibly much farther north, and that it may even have debouched near Laoag, many kilometers north of Vigan. As the Abra breaks across prominent geologic structures in the lower part, it may be an antecedent stream with a history dating from an earlier physiographic cycle.

Bicol River.—Bicol River is the most important river in southeastern Luzon; it rises in Bato Lake and flows northwest through the volcanic plain at the foot of Mount Isarog and empties into San Miguel Bay. The most important town on it is Naga (Nueva Caceres), which is located at the head of navigation for ocean-going interisland vessels. Above this town the river is navigable for a considerable distance for flat-bottomed boats, especially in times of high water. In the uppermost reaches a unique system of transportation is sometimes used, a dugout towed by a carabao. This mode of transportation is used because the stream is exceedingly shallow in some places, while in others it is much deeper. The boatman finds it easier to be towed by his animal than to propel the boat by poles, especially since the carabao can swim in the deeper water and does not mire in the shallow, muddy places where he walks.

Angat River.—Another large river, rising in the eastern cordillera, which may be of great future importance, is the Angat. This stream debouches onto the Manila plain; it is not navigable except for dugouts and rafts, as there are many rapids throughout the greater part of its course. A large

project for a new water supply for Manila is being planned on this stream. The river, incised deeply in a great lava flow on the edge of the cordillera (Plate 28), is one of the most picturesque in Luzon. The water-power possibilities on the Angat are of considerable importance.

Bued River.—The Bued rises on the Baguio Plateau and flows southward as a typical mountain torrent through a cañon of remarkable beauty. This cañon has now become notable as the route of the wonderful Benguet Road. Nowhere has the terrific destructive power of running water been better illustrated than in this gorge and, as a consequence, the maintenance of this highway to Baguio has become a serious problem, both financially and from an engineering standpoint. Torrential rainfalls in a region of high relief and of more or less shattered andesite make this location exceedingly hazardous. Plate 20, fig. 1, shows a photograph of dipping conglomerate beds in the lower cañon, near Klondike's Hot Springs. These beds were once thought to be at the base of the Tertiary series, but there is evidence that they are far above that position.

Paracale River.—Paracale River is located on the east coast; it and several other streams appear to be drowned in part. They are short and would not merit especial attention were it not for the rich gold placers which formerly made them of great local interest. These are nearly exhausted, and the fleet of dredges has almost vanished. In 1915 there were nine operating; now there is only one.

Pasig River.—Pasig River is the shortest, and yet the most important of the larger island waterways; it has its source in Laguna de Bay and debouches in Manila Bay. Its total length is not over 24 kilometers. The fall of this stream is slight, as it flows through almost flat country. While it does not carry the greatest volume of water-borne freight in the Islands, the river usually is choked with interisland boats and launches in its lower part, within the limits of Manila. Vessels drawing over 3 meters come into the river to Manila, but only launches and very light-draught boats proceed above Manila. The tide runs up this stream as far as Fort William McKinley, about 12 kilometers. At this point the river cuts through gently folded tuff beds, affording about 15 meters of section. This is important, geologically, because it gives an excellent opportunity for the study of the composition of the plain and gives a clue to

its geologic history. This rock also is of considerable economic importance.

In order to understand the courses of many of these rivers one must consider the earlier physiographic cycles in the history of the island. Many of them, like the Abra and the Pasig, were developed on a Pleistocene plain and continued to flow across important and oftentimes resistant geologic formations which were uplifted across their courses. One of the best instances of this is Trinidad River, in Benguet. Eveland(237) suggested but did not elaborate this drainage history. It remained for Dickerson to complete the study of this interesting Baguio physiography.

LAKES AND SWAMPS

The true lakes in Luzon are Laguna de Bay, Taal, Canaren, Bato, and Buhi. Paoay, Cagayan, Pamplona, Mangabol, and Candaba are merely great swampy areas, whose size changes with the seasons.

Laguna de Bay.—This is the largest lake in the Archipelago and the most important in the life of the people of the Islands. The greatest length and width of water are 40 and 34 kilometers, respectively. It is very shallow throughout. The contour of this body of water is perhaps the most characteristic thing about it, being roughly heart-shaped and having three prongs or fingers projecting northward. It seems probable that this lake covers a stretch of low country once occupied by the sea, the latter having been cut off by the deposition of a great amount of tuff, which was gently folded, forming a dam on the western side of the depression. The slightly arched tuff beds can be seen plainly where Pasig River cuts through them near Fort William McKinley. The high land on which the United States Army post is situated is due to the bowing up of these beds. The fact that this lake basin formerly was occupied by an arm of the sea or a much larger lake was proved to my satisfaction by the finding of terraces on Binangonan Peninsula. Adams was unable to see these, and also cast some doubt on the evidence produced by the finding of Recent marine shells on some of these benches. It is admitted that these shells may have come from kitchen middens, as Adams suggests; but the marine-terrace theory seems more nearly correct, since the latter alone will satisfactorily account for the presence and ap-

pearance of the benches. In a region of excessive rainfall terraces would not be so well preserved as they are in more-arid regions. The recent military maps of the region leave little doubt that these are marine terraces, but they may be lake terraces.

Around the eastern shores of the lake, on Jalajala Peninsula, and on Talim Island there is considerable basalt in the form of flows and agglomerate. The shape of the lake suggests former well-defined north and south valleys, whose width, shape, and extent have been modified by the flows and the tuff deposits. On the east side of this lake is a remarkable topographic feature (Plate 14), which I can explain only by faulting.

Lake Taal (Bombon).—Lake Taal is situated about 65 kilometers due south of Manila. It is roughly 25 kilometers by 15 kilometers, and its surface is only about 1.5 meters above sea level. Near the center is a small island on which are the main crater of Taal Volcano and several subsidiary cones. It has been studied by several geologists, but particularly by Adams.(21) As his views appear to be as satisfactory as any yet expressed, and as he incorporates in his discussion the important statements contributed by previous writers, the following quotation is made from his paper:

> Taal Lake is evidently a caldera formed by peripheral and radial faulting and the subsidence and collapse of the many cones which have been formed within its area during prehistoric eruptions. The process of formation has been continued to a small degree during historic time.
>
> The fact that the caldera is occupied by a lake prevents in a large measure the study of its origin. However, in the brief notes concerning the two eruptions of Taal, it is recorded that within Taal Lake a new cone arose as an island and subsided, leaving as its remnants two small islands which lie to the east of Taal Volcano. In another eruption, a portion of the shore of Taal Lake near the former site of the settlement of Taal subsided below the water. Many who see the sheer face on the west side of Mount Macalod form the opinion that a large mass of the mountain has subsided into Taal Lake, and as substantiating this idea it is pointed out that the deepest part of the lake is found near this mountain. While studying the shores of the lake it was observed that in certain parts they are precipitous, while in others they are eroded into gentle slopes. It may be that some of the precipitous shore lines are due to recent faulting and displacement, but it will require a detailed study to prove this.

The evidence for Adams's conclusion cannot all be given here, but the two most important points are the existence of faulting in the region surrounding the lake, and the shape of the profile along a line drawn through the center of the lake. The con-

sensus among geologists who have studied the lake is that a combination of circumstances—explosions, subsidences, etc.—caused the present condition of things. The structures and physiography exhibited by the caldera of Kilauea, Hawaii, are in my opinion remarkably suggestive in this connection.

There are many other, smaller calderas occupied by water in the region where Taal is located. These are particularly numerous and a prominent feature of the topography in the vicinity of San Pablo, Laguna. Many of them are perfectly circular and of unknown depth. They are of various dimensions; some are only a few meters in diameter.

Lake Canaren.—On the old Jesuit maps of Luzon Lake Canaren is shown as a coalescing of several tributaries and, strangely enough, according to the maps, water seems to flow into it from almost any direction, and out of it either toward the Agno, north, or toward the Pampanga, south. The area covered by this lake is only about 40 square kilometers. It is little more than a swamp.

Lake Paoay.—Paoay is a small lake located in the dune area of Ilocos Norte and owes its origin to ponding by wind- and water-borne sand.

Other lakes, such as Bato in Albay Province, and Lake Cagayan, are little more than bodies of water that fluctuate with the seasons.

Pratt(499) has written a special paper on Philippine lakes to which the reader is referred for details of the lakes of Luzon.

CORDILLERAS AND PLAINS

THE WESTERN CORDILLERA

The western cordillera is generally known as the Zambales Range and extends from Olongapo north into Pangasinan Province. Another part of this range consists of a cluster of volcanic stocks in Bataan Province. This range of mountains is not by any means a continuous one; there are a few isolated high peaks, but in the main the range is not greatly elevated. The highest point is Mount Pinatubo. This has never been accurately measured, but is in the neighborhood of 1,800 meters high. Very little geologic work has been done in this cordillera. Von Drasche(200) worked in the vicinity of Iba, and Fanning,(250) at a few points near Agno and Alaminos in Pangasinan. I(568) have been on the second highest peak of Pinatubo (about 1,700

meters), which is composed of trachytic andesite, and on one of the high peaks of Mount Mariveles (about 1,672 meters high), which is also andesite.

The principal pass across this region is from O'Donnell, in the central plain, to Iba. There is another, well-defined trail, from Mangatarem to Infanta at the southern end of Dasol Bay. There is also a good road from Alaminos to San Isidro, and in the southern part there is a telegraph line from Olongapo to Dinalupijan. With the exception of occasional expeditions of United States Marines, this trail is very little used by anyone but the local inhabitants.

The northern Zambales mountains are not covered with a particularly heavy growth of timber; in fact, many parts, like Pinatubo, are bare up to about 1,500 meters, and the last 300 meters are covered with a dense mossy forest; this is due to the excessive moisture from the clouds which continually hang about the summits. In Bataan Province the vegetation is very dense, and the forests possess considerable commercial value. The Cinco Picos Range, however, is almost bare.

In general, the rocks of this range are volcanic extrusives, andesites, with marls and shales on the flanks, though serpentine, cherts, and schists are also found there.* The Cinco Picos Range, however, on the western side of Subig Bay, consists of a totally different rock from that found on the east side, being a dense pyroxenite.† There are no active volcanoes ‡ along this range, and the old volcanic stocks are pretty well eroded.

There is a considerable stretch of alluvium from Subig northwest to San Narciso. The country here is very dry in certain seasons, and owing to the composition of the soil the water sinks

* Elicaño has noted diorite in this region, east of Masinloc.

† The effect of the geology upon geodetic calculations was very effectively demonstrated recently in this part of Luzon. A considerable discrepancy between the astronomically determined points and the trigonometric stations near Olongapo was found to exist. The small Cinco Picos Range, which consists of pyroxenite, lies to the west of the stations, and the great andesitic mass of the Zambales lies to the east. The observers expected the plumb bob to be deflected in an easterly direction, owing to the main mountain mass being to the east; but the deflection was to the north, as if one component of the forces was to the west, toward the smaller mass. Not until an examination disclosed the denser rock in the Cinco Picos (to the west) could the discrepancy be explained.

‡ Mr. Snyder, of the Bureau of Lands, reported that smoke was seen issuing from the top of one of these peaks.

rapidly, giving to the country the appearance of a semiarid region.

The physiography and geology of the western side of the Mount Pinatubo cluster is discussed by me in a paper published in 1910. In this I call attention to the great depth of valley filling of loose detritus, due to the torrential wash from the Pinatubo Mountain group. Aglao Valley has sections showing loose sand and bowlders from 30 to 60 meters deep. Indications of recent marked uplift are to be seen in this valley where several stages of terraces and entrenchments of the stream are revealed.

Two formations in this general Zambales region deserve especial notice; namely, the foraminiferal tuffaceous marls on the coast near Santa Cruz, described by von Drasche and Karrer and referred to the Pliocene, and the great mass of agglomerate on the eastern flanks of these mountains in the vicinity of Floridablanca and north toward Camp Stotsenburg.

Asbestos and copper are found in this region, but there is no exploitation. The heavy red soil, laterite, on Mariveles Mountain is in places almost rich enough in iron to suggest the possibility of smelting it. In this connection also attention should be called to the extensive black sands on the Bataan coast, referred to in the chapter on Economic Geology.

THE CENTRAL PLAIN OF LUZON

The principal interior plain of Luzon is the chief place of settlement in the Philippine Islands. It is, roughly, 192 kilometers long, stretching from Manila Bay on the south to Lingayen Gulf on the north, by 112 kilometers wide. On the west it is bounded by the Zambales Mountains, and on the east by the eastern cordillera. This plain was probably the site of an ancient arm of the sea, a fact to which attention has been called by a number of geologists, among them Adams,(21) who has drawn a hypothetical map of the Tertiary geography of the central portion of Luzon.

Composition.—In the northern and southern portions the central plain is largely composed of alluvial material with pyroclastics, as shown by well sections and river banks. There are the delta regions of the Agno in the north and Pampanga River in the south. The southeastern part is largely made up of pyroclastics, as can be seen in railroad and river cuts and numerous well sections. That this pyroclastic material ex-

tended to a considerable depth is shown by a well section from Pasay near Manila.

TABLE 7.—*Section of well at Pasay, Rizal Province, Luzon.*

Feet.	
0– 18	Soil, sand, and sea shells.
18– 83	Gray and yellow silt with pebbles, shells, and calcareous concretions.
83– 87	Fine to coarse basaltic pebbles and tuff.
87–113	Yellow-gray sand, some clay, fragments of soft tuff.
113–160	Yellow-gray tuff.
160–180	Yellow sand and tuff, small basaltic pebbles.
180–463	Light, yellow-gray tuff, partially with basaltic pebbles.
463–483	Fine dark sand, some clear grains; tuff, basaltic pebbles.
483–546	Fine-grained tuff; light gray.
546–570	Dark sand, some clear grains.
570–594	Tuff, with small basaltic pebbles.
594–634	Yellow clay with small basaltic pebbles.
634–690	Dark sand.
690–713	Fine gray tuff.
713–743	Basaltic pebbles and fragments of tuff.

Logs of wells at Fort William McKinley, near Manila, show the same materials to a depth exceeding 300 meters.

Physiographic features.—At first glance, the most striking physiographic features of the central plain are: (*a*) The drainage system; in the north the rivers flow to the north and in the south to the south; this may be accounted for by warping, or merely by irregular deposition of detritus. Civil engineers thoroughly conversant with this region maintain that it would take very little to divert the Agno south toward Manila Bay.* (*b*) The single extinct (Pleistocene or Pliocene) volcanic cone of Arayat, standing isolated in the center of this great flat. (*c*) The one lake and two large swamps located in the eastern part. (*d*) The vast delta region of Pampanga River which bounds Manila Bay on the north.

Origin.—The origin of the central plain of Luzon can be determined only after a study of the materials that compose it. Some, including Herrmann,(317) have traced it to faulting; that is, the valley represents a Graben with horsts of upstanding material on either side, very much as in the Rhine Valley.

* Tradition has it that not over one hundred fifty years ago one could go by boat from Manila to Lingayen over this plain.

It is very certain from both topographic and structural evidence at many points along the periphery of this plain, that faulting has occurred on the west side near Banban, where the tuff is exposed in an east-facing escarpment of westerly dipping beds. The throw of the fault here is at least 60 meters. Other suspected faults, such as that running east and west along the southern face of the Benguet mountains, and another nearly north and south along the front of the eastern cordillera near Montalban Gorge, lend support to the theory of Herrmann. Yet, on the whole, one is constrained to hold to the view that the valley is largely due to filling by detritus from the mountains flanking it, accompanied by the slow elevation of Luzon as a whole and by the deposition of pyroclastic material which has come from several vents within the limits of the plain and those on its margin. The log of a well at Arayat, Pampanga, in the lower central part of this plain is given as Table 8.

TABLE 8.—*Log of well No. 492, Arayat, Pampanga; depth 600 feet, pumps 50 gallons per minute.*

[Determinations by Geo. I. Adams.]

Feet.	
0– 26	Brown sandy clayey soil.
26– 38	Dark grayish sandy soil.
38– 85	Bluish clay with bits of shell.
85–100	Dark-colored clay with bits of shell.
100–109	Brownish, fine, evenly grained sand.
109–120	Medium-grained sand with pebbles.
120–125	Dirt with fragments of pebbles.
125–138	Clay with bits of igneous pebbles and shells.
138–160	Sand and unsized pebbles.
160–179	Clay with fragments of igneous pebbles and bits of shell.
179–190	Light-colored, medium-grained sand with some small pebbles.
190–200	Clay with unsized pebbles and igneous fragments.
200–222	Clay with unsized pebbles.
222–244	Dirty gravel.
244–263	Medium-grained sand.
263–285	Light-colored, evenly grained sand.
285–320	Light-colored sand with small pebbles.
320–330	Light-colored, medium-grained sand.
360–400	Medium-grained sand.
400–425	Fine-grained sand.
425–480	Medium-grained sand with pieces of pumice.
480–500	Coarser sand with pumice.

TABLE 8.—*Log of well No. 492, Arayat, Pampanga; depth 600 feet, pumps 50 gallons per minute*—Continued.

Feet.	
500–518	Fine sand.
518–526	Medium-grained sand.
526–545	Sand with pumice.
545–555	Medium-grained sand.
555–559	Coarser, light-colored sand.
559–574	Medium-grained sand.
574–580	Light-colored material of small rounded pebbles of arenaceous clay.
580–600	Medium-grained sand.

THE ILOCOS COAST STRIP

This physiographic unit extends along the western side of Luzon from near the head of Lingayen Gulf north to Cape Bojeador, and comprises most of La Union and Ilocos Sur Provinces and the western one-third of Ilocos Norte. In the widest portion it scarcely exceeds 20 kilometers. This is a fertile and populous region and is peopled by the thrifty and hard-working Ilocanos.

The district consists largely of an elevated coastal tract, in part of raised coral and in part of alluvium overlying older

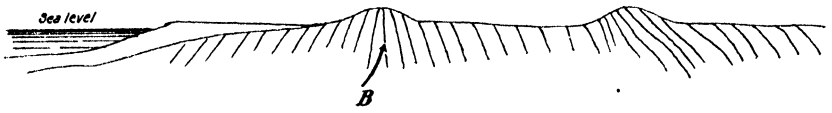


FIG. 3. Geologic section near San Fernando, La Union.

sediments, as indicated by fig. 3. The plain is bounded on the east by an escarpment, which in part is due to a fault and in part is the edge of andesitic extrusives. Across it flow large streams, the Abra and the Laoag, which debouch onto it through striking water gaps in the older and harder rocks to the eastward.

Vigan and Laoag are the largest cities on this plain. The influence of topography upon a people is clearly exemplified here, as the shortage of arable land has forced these people to unusual activity and thrift as compared with some of their neighbors.

THE CORDILLERA CENTRAL

The Cordillera Central begins at about the latitude of Lingayen Gulf and extends to the northernmost point of Luzon. It is not a single range, but consists of two or three parallel ranges. The eastern cordillera and the Cordillera Central start from what Adams calls the "Central Knot," which is the Cara-

ballo Sur in northern Nueva Ecija and Nueva Vizcaya. The principal range of the central cordillera is the Polis Range, about 40 kilometers east of Cervantes. This cordillera keeps its high elevation practically throughout the whole extent and is a region of great rainfall and excessively steep slopes upon which landslides are of frequent occurrence.

The head of Bued River Cañon is marked by some very interesting landslides which not only are producing rather pronounced changes in the topography of that region, but also have become of first importance since some Government public buildings have been endangered.

Just before one reaches the Baguio Plateau proper, traveling along the Benguet Road, one climbs to a bench which is largely due to subsidence of material from the valley sides. There is here a broad amphitheaterlike area, 2 or 3 kilometers long and a kilometer or so wide, which remarkably simulates the cirque-like head of a glaciated stream. At the upper end of this valley there is a huge crack or series of cracks running around the hills, about as the "Bergschrund" at the head of a glacial cirque does. On the west side of the Benguet Road the greatest slip can be easily studied. There is a fault here in loose tuff, sinter, and volcanic breccia, amounting to at least 50 meters. The slip plane has an angle of from 55° to 60° and at this point trends north and south. In fig. 4 the plan and the cross section of these slips are shown. The sections were made by Lednicky in January, 1915, when he was called upon to report upon the Hospital Hill slide. I visited this region during several previous seasons, and in the spring of 1914 I measured the subsidence, which then amounted to 10 meters, and the rate of movement, 2.5 centimeters an hour. As this material is all very loose and only held together by clay, it is absolutely certain that there will be other slides behind the present one and the hospital buildings, unless moved, will ultimately be wrecked.

This subsidence is due to several factors. Undoubtedly, the saturation of the loose materials with water is the prime important cause; another cause is the high angle of the valley walls, which is far above the angle of repose. The ultimate cause can probably be traced to the solution of limestones found far below at the bottom of Bued River Cañon, notably at the foot of the Zigzag, which would permit the leaching out of the rocks and thereby cause the slumping of the material above.

Similar and even greater slides occur much farther north in the Mountain Province, notably at Sagada, where a slide extends

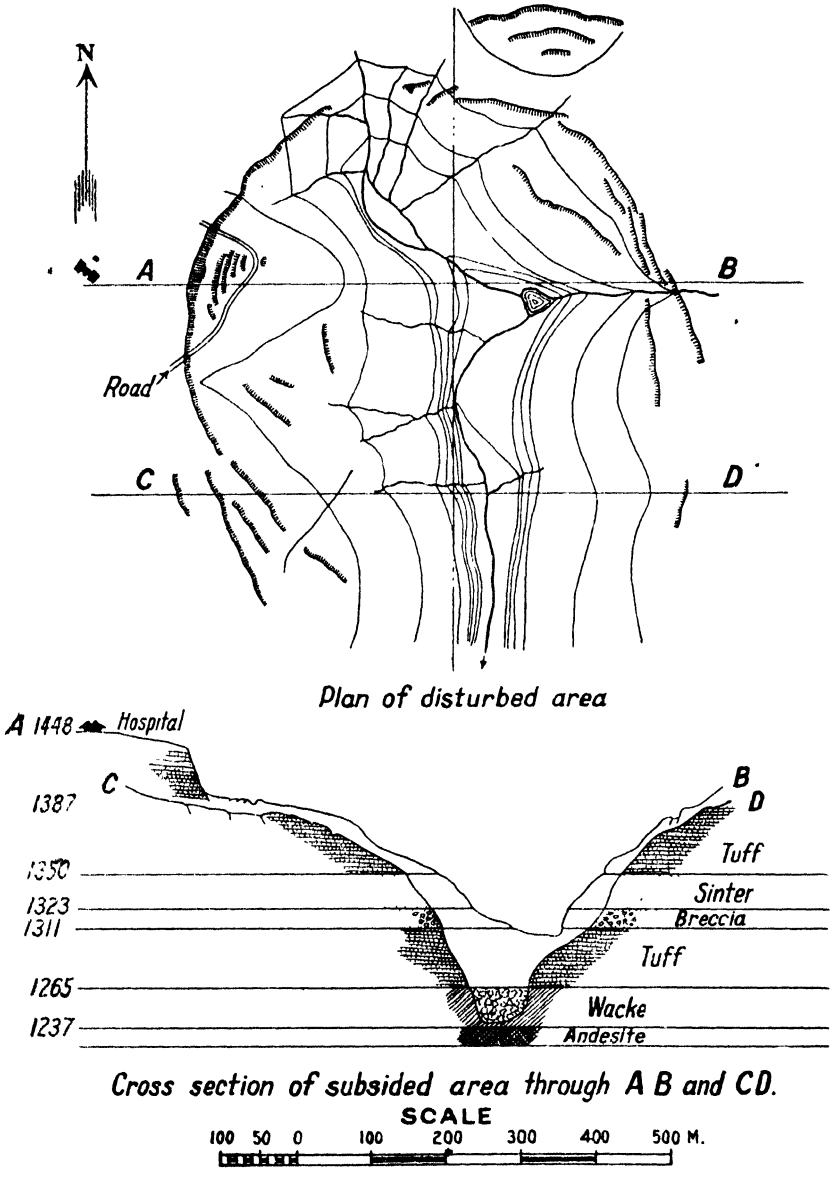


FIG. 4. Plan and section of the hospital-hill landslide near Baguio.

over even a larger area; there the subsidence in 1914 amounted to over 3 kilometers. The fault crack, following the periphery of the valley head, when seen by me was at least 3 kilometers long, and a large Igorot village was gradually settling into the cañon without any particular disturbance to the inhabitants.

The Catholic church which had been located, unknowingly, over the fault line was tipped over at a considerable angle, was partially wrecked, and had to be abandoned.

It is my opinion that many of the plateaulike areas in northern Luzon, and especially many of the benches in the valleys, are due in part to fill as a consequence of these enormous subsidences of the loose, water-saturated terrane. These slides will not cease until the angle of repose for this kind of material is reached.

A remarkable feature of this region is the torrential precipitation; this, in conjunction with the high altitude and comparatively short distance from the sea, resulting in great declivity of the streams, makes for very rapid and pronounced erosion. A study of the processes of denudation and sedimentation in a region like this would yield enough material for a separate chapter. One characteristic of much of the sediment produced under such conditions is the coarse heterogeneity and lack of well-rounded particles as compared with sediments under quieter conditions.

As the political unit known as the Mountain Province includes most of the central cordillera, a study of that province by me, which was published in 1915, will be largely repeated here with such modifications as later work and maturer judgment demand.

The area of the Mountain Province is 16,649 square kilometers. The highest point is Mount Pulog, 2,924 meters. The largest river in the province is the Agno, which flows southward from Mount Data. The capital is Bontoc, in the heart of the Igorot country, but the best-known town is Baguio, the former summer capital of the Philippines. The province is traversed north and south by three prominent mountain ranges: the Malaya Range on the west, about 1,800 meters high; the Cordillera Central, 1,800 to 2,400 meters high; and the Polis Range on the east, 1,500 to 2,100 meters in elevation.

Topography.—There are three distinct types of topography in the region under discussion, and these are directly influenced by the nature of the geologic formations. First, in the country west of the Polis Range the formations are mainly volcanic, and we find there an irregular, rugged, accentuated relief. The elevations vary from 360 to 2,400 meters or more. Second, east of this range, the formations are folded sediments, giving rise to a more regular topography, and some of the hills and mountains are nothing more than tilted blocks of sandstones and shales.

On the eastern slopes these present long, gentle inclines, but to the west there are steep escarpments with here and there a saw-toothed sky line. As one goes farther east, approaching the valley of the Cagayan, the mountains become mere foothills.

In the eastern portion between the high country and the low country just referred to, and therefore more properly a part of the intermediate uplands, there is a stretch which has been called by Worcester "No Man's Land." The people inhabiting this section will be referred to in a subsequent paragraph. The topography consists of medium-sized hills, 360 to 450 meters high, which are due to cross folding of the original flat-lying sediments; that is, to the east and west folding has been added a north and south series of folds. This produces low, hummocky hills and little, "pockety" valleys, or hollows.

The third distinct type of topography is the high plateaus such as the one at Baguio and the one on Mount Data. These, as pointed out in the chapter on Physiography, are regions of mature to old-age topography, probably representing remnants of peneplanation in an earlier cycle of erosion which, through extraordinary elevation accompanied by faulting, have been set off from the surrounding country of more-recent and more-marked youthful topographic relief. The most remarkable of the plateau remnants is that of Mount Data, which is a high (2,600 meters) block mountain made up almost entirely of beds of tuff and andesitic agglomerate more or less in a horizontal position, standing out very prominently in the landscape, marked on at least three sides by very imposing fault scarps. The topographic unconformity between this physiographic unit and that of the surrounding country is even more marked than in the case of the Baguio Plateau. The mountain has never been accurately mapped nor even roughly outlined. The eastern escarpment is very imposing as revealed by the accompanying photograph (Plate 19, fig. 2); it is at least 500 meters in height with an average slope of about 60°. Over the side of this eastern wall plunge several considerable streams in wonderful cascades. One of these takes a total drop of 500 meters in four or five plunges. In some places the walls are perpendicular. The surface of this plateau is very much like that at Pauai (Haight's), near kilometer 57, but owing to the heavy timber of the mossy-forest type it is difficult to make out the exact configuration of the surface. A fairly deep cañon cuts through the middle of it. The northern part is fairly level, and in places in the rainy season there are

standing water and more or less swampy ground. This has given rise to the tradition that there is a lake on the top of Mount Data. At the time of my visit at the beginning of the rainy season I saw nothing that could be called a lake.* The only limestone that I saw on or about the mountain was a small residual patch of badly weathered limestone (Malumbang?) on the southeast slope very close to the Bontoc Trail, at an elevation of approximately 2,200 meters.

At the extreme north end of this plateau there is a high rock, from which the best panorama I have seen in the Philippines is obtained. This rock is an agglomerate, with water-worn bowlders firmly cemented in an andesitic matrix. I believe that Mount Data is to be correlated with the Baguio Plateau.

Kilometer 81.—At about kilometer 81 on the Baguio North Trail, a half kilometer east of the trail, there is a small plateau remnant with a remarkable hanging valley. The topography of this plateau remnant is distinctly old-age or at least very mature, and at the south end there are a precipitous cliff and a large slide. In the upper portion of the slide there is an excellent section which shows one interesting feature; namely, an old buried soil 0.5 meter thick, which at a distance has the appearance of a coal seam. A sample was obtained and it proved to be merely a very heavy deposit of humus; it is not even peat. There is about a meter of sand and tuff above this, with the present soil on top. The elevation of this old plateau remnant is about 1,000 meters.

Sagada.—It has been suggested by some that Sagada is another plateau remnant. I have not visited the region for ten years, but from my recollection of that country I am of the opinion that it does not correspond to the areas under discussion. There is a considerable bench near the Sagada Mission which is due to subsidence. However, there may be other areas in the vicinity of Sagada that I did not see.

River terraces.—As one travels north on the Baguio-Bontoc Trail, particularly in looking eastward across Agno Valley, several well-defined river terraces and elevated benches are distinctly visible. These are far from the river, high on the sides of the Polis Range. Undoubtedly, these are to be correlated

* Merrill, who visited this locality in 1906, says that there is a small shallow lake with no outlet on the right of the trail toward the northern end of the mountain. It is not more than 100 meters in diameter, and has water in it at all seasons.

with such terraces and benches as have been noted in Bued River Cañon near the Kias Trail, and in the country northwest of Trinidad.

Climate.—The climate in this region shows a complete gradation from subtropical in the bottoms of the intermontane valleys (for instance, at Cervantes) to temperate in the more elevated portions. In the winter months thin ice forms at Pauai, on Mount Data, on Pulog, and at other high points.

As there is no meteorologic station in the Mountain Province, except at Baguio, figures for the rest of the province cannot be given. Rainfall is excessive at certain seasons, and the rainy season occurs at different times in different parts of the region. Again, we find the Polis Range the great dividing line. On the eastern side of this prominent topographic feature, in Ifugao for instance, the seasons correspond more nearly to those that obtain in Cagayan Valley.

Hydrography.—The prominent features of the hydrography are the three principal streams, all rising on the slopes of Mount Data. The Abra flows almost due north until it approximately reaches the town of Dolores, where it turns west by south and comes out to the coast just south of Vigan, cutting through a hard igneous coast range. The second large stream flows northeast and reaches the sea by way of Cagayan. The third is the Agno, which also rises on the slopes of Mount Data, but flows due south to the central plain of Luzon. None of these streams is navigable in the area under discussion. The main drainage lines in the area are well defined and doubtless structural, north and south, with the usual attendant tributaries, influenced by purely local or minor topographic features. The physiographic histories are too complicated or too little known to be discussed at further length.

Vegetation.—The region as a whole cannot be said to be a forest region. There are areas, like the slopes of the Polis Range, that are fairly abundantly supplied with timber, chiefly pine (*Pinus insularis*); and there are portions of the territory clad only with scattered timber, little of which is suitable for anything but fuel (for instance, around Bontoc and Lubuagan), while in Ifugao, around Banaue, there is scarcely a stick of standing timber. There is, of course, the usual vertical differentiation in the plant distribution which is pretty constant throughout the Malaysian region—that is, the characteristic strand flora of Malaysia along the seashore—the lowland forests generally ascending to approximately 750 to 1,000 meters; the mossy forest

on exposed peaks and ridges, characterized by the absence of lowland types, the presence of some temperate-zone types, and the enormous development of mosses, hepatics, lichens, and epiphytic ferns, orchids, etc. In northern Luzon there are large areas at and above an altitude of 1,000 meters where the pine tree is dominant. Where the forest has been destroyed vast areas occur that are occupied by the high cogon grass (*Imperata*), while at higher altitudes even coarser grasses, such as the runo (*Miscanthus*), become dominant. The flora that Merrill * found on Mount Pulog is typical of the northern Luzon high-mountain region. The low-country vegetation is at present found nowhere in the region. It is important to bear this in mind, because of a certain fossil flora recently found at a high altitude, which is described in the chapter on Paleontology.

Population.—The indigenous people, Igorot, Ifugao, Kalinga, etc., of this northern country are essentially primitive and in most instances have been little influenced by outsiders. While a considerable number of tribes and corresponding dialects have been noted, the people are fairly homogeneous.

General geology.—A cross section such as I made in traveling from the west coast at Tagudin northeastward to the edge of Cagayan Valley gives one a good general idea of the formations and the structure of the region (fig. 5). Near the west coast are found gently folded shales and sandstones, which become more inclined toward the Malaya Range, and more contorted toward the east. The Malaya Range is essentially a mass of porphyry or, to be more exact, andesite. Some phases of it are aphanitic and distinctly bluish green. The town of Cervantes is situated on a small tongue of high ground between the Abra and one of its branches. The rock underneath is practically the same as that found in the high land on each side of the town. Toward Bontoc there is a similar andesitic mass with, however, several large outcrops of quartz. At Bagnen and Sagada, tuffs and limestones overlie the andesitic mass. These tuffs dip 20° southeast and, though they are topographically higher in places, the limestones appear to be stratigraphically above them. Subsidence explains their lower position. Between Sagada and Bontoc there are extensive rocks, almost entirely andesite and dacite, but east of Bontoc diorite and granite appear. The belt of granite rocks is only 8 to 10 kilometers wide. There is more andesite or, rather, it is very fine grained, almost an

* Philip. Journ. Sci. 5 (1910) Bot. 287.

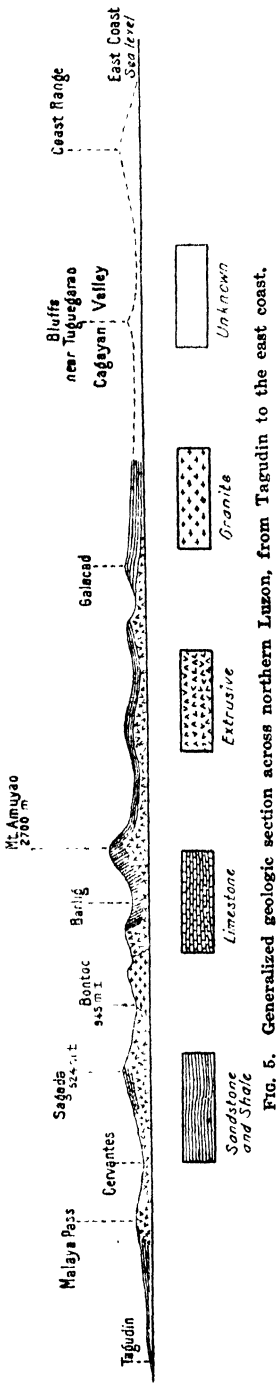


FIG. 5. Generalized geologic section across northern Luzon, from Tagudin to the east coast.

aphanitic phase of diorite, almost to the town of Barlig, where steeply dipping, sandy shales are encountered again, with the inclination toward the south. Sandstone and sandy tuff make up the main mass of Mount Amuyao which, like Mount Santo Tomas in Benguet, may owe its elevation to faulting; from there to Cagayan Valley the same sediments are found. Occasionally, as at Natonin, there is an area of extrusive rocks overlying the sediments. I saw no limestone east of Barlig, but farther north on the crest of the range back of Tinglayan, limestone cliffs could be made out with the glass, at nearly 2,000 meters elevation.

Granite.—The plutonic rocks already mentioned consist of granite and diorite. Granite outcrops in a rather narrow belt, about 4.8 kilometers east of Bontoc, and along the valley of the Saltan at Balbalasang and for some little distance down that stream. It appears to be a long intrusive mass whose long axis is northwest and southeast. It is a typical quartz-feldspar-biotite granite and has a grayish to glaring white appearance in the field. The feldspar is milky white. No microscopic examination of the feldspar has been made. The jointing in this formation is particularly marked, and its strikes and dips were noted as follows: North 20° west, 57° southeast; east and west, 75° east; north 60° east, 30° (?). This granite is probably an extension of the large intrusive mass encountered farther south in Benguet.

Diorite.—The diorite is a quartz-plagioclase-hornblende variety with some orthoclase and lies on both sides of

the granite. Bordering the granite, and apparently in the diorite, are several large quartz bodies, which will be referred to again. These plutonic rocks are undoubtedly much more extensive than they appear to be, but they are concealed by the overlying extrusives. I consider the diorite to be the basal formation, and the granite an intrusive of rather recent date.

Extrusives.—Von Drasche has described the typical extrusives found in this region, and there is little to add to his list. Andesite is the principal type. Von Drasche apparently makes no mention anywhere of dacite, a glaring white rock with small phenocrysts of clear quartz in a dense, creamy white, aphanitic groundmass. I found this well developed near the junction of the main Cervantes Trail and the Sagada Trail, nearly 6 kilometers south of Bontoc. The relation to the rest of the extrusive mass is hard to make out, even in the fresh cliffs along the trail. This rock is not essentially different from the Corregidor rock, mentioned by Becker.

It seems that immediately west and north of Bontoc is one of the vents from which much of the volcanic material in this region reached the surface.

The list of extrusives compiled from both von Drasche's and my own observations includes basalt, andesite (pyroxene), andesite (hornblende), andesite (agglomerate), dacite, and tuff.

A description of the extrusives, as already published for the Benguet region,(560) shows no essential difference between the rock types of the two districts. Their distribution is shown on Plate 39.

The sedimentary rocks in the region include limestone, marl, tuff, tuffaceous sandstone, sandstone, shale, conglomerate, sinter (calcareous and siliceous), and travertine.

Limestone.—In the high-mountain region of Luzon limestone is widespread but not continuous. It consists of remnants here and there, generally on the high-mountain tops, and that it formerly extended over a much greater area is patent. Plate 39 shows some of the localities where it may be found now. Probably the most interesting development of this limestone is at Sagada, where it projects from the soil in great masses. The bedding planes can be distinctly made out, about 20° southeast (Plate 3, fig. 1). On the weathered surfaces the limestone is bluish gray, but on fresh fracture it is cream white to reddish. Plate 3, fig. 2, shows the characteristic spirelike forms produced by the dissolving action of the heavy rainfall of this

region along joint planes. A thin section of this rock showed innumerable fragments of the well-known Mio-Pliocene marine alga, *Lithothamnium ramosissimum* Reuss. This limestone is, then, equivalent to the upper limestone of Cebu and of many other parts of the Archipelago.

A similar limestone near Baguio, about in the same topographic situation, Dickerson believes is Malumbang (Pliocene). At Sagada, the limestone contains numerous sinks, and some caves of no inconsiderable proportions in which the Igorots bury their dead. One of these caves has one chamber as large as the auditorium of a small theater, and its passages are said to contain a total length of 5 kilometers. I explored only a small part of the cave as I found that it does not differ, essentially, from scores of other limestone caves. It is interesting, but not of fundamental importance. The heavy wash of torrential water has not permitted a great accumulation of detritus in these caves, and probably little of archeologic or paleontologic value would be found in them.

At Sagada, just below the Mission of Saint Mary the Virgin, and above the limestone at the large cave, I found what appears to be a purely local development of conglomerate. It consists of a sandy reddish matrix with limestone pebbles in it. It is both topographically and stratigraphically above the limestone which von Drasche thought was the uppermost formation. May this not be the equivalent of the Bued River conglomerate described in the chapter on Stratigraphy?

Marl.—Von Drasche has called attention to the marly layers intercalated in the upper limestone near Sagada. I also noted such layers in several places on the road south of the mission; but the layers are thin and, unless the material might find some economic application in connection with the limestone, do not seem to be of great importance. The marl is buff colored.

Tuff.—As would be expected in a region of great volcanism in the past, tuff beds are a dominant feature. At Sagada, perhaps, is the best section. Here Father John Staunton opened a quarry in this material to get stone for a new church. The face of the quarry is now (1922) about 23 meters high. At the bottom is 1 meter of bluish black, shaly-looking rock which is very fine grained; this is succeeded by 6 meters of an almost solid bed of tuff which varies in texture; above this, 7 meters of yellow-stained beds of shale; and at the top, tuff beds 1 to 3 meters in thickness. In the face the stratification appears to be

nearly horizontal, as the quarry is opened approximately along the strike. The dip, however, is actually 20° southeast. In the shaly portions are many leaf impressions of which I secured some excellent specimens through the kindness of Mr. McBrust, the engineer of the Sagada Mission. This flora is described in the chapter on Paleontology.

The conclusion to be drawn from the presence of these fossil leaves is that there have been recent great land movements in this part of Luzon. It does not indicate a change of climate in the Philippine region, except such as would come from a change in elevation. All the evidence on hand supports the assumption that there probably has been little or no regional change in climate throughout the Tertiary or post-Tertiary. The tuff beds are probably not older than Pliocene.

Throughout this region, but usually near the volcanic area, are beds which can with difficulty be differentiated from tuff on the one hand and true sandstone on the other. This material is found in its most puzzling aspect at Lubuagan, the capitol of Kalinga. The constituents of both the tuff and the sandstone came from the break-up of basic igneous rocks. Whether the material from which they were derived was disintegrated by explosion or by subsequent erosion can only be told by examination of the shape and condition of the component grains. The point is that the composition in both cases may be much the same. As one goes eastward it becomes easier to make distinctions.

Sandstone.—A typical exposure of what may be termed the Kalinga sandstone is found on the banks of Chico River, near the Nipan rest house. Here the sandstone and alternating shale beds are exposed for over a kilometer on the west bank of the river. The dip of the beds is 65°, slightly north of west. The sandstone is a coarse grayish to buff material which shows plainly its derivation from andesitic rocks. Along the bedding planes, ripple and wave marks show very plainly and abundantly. Here also I saw some undeterminable plant impressions, apparently of long-stemmed reeds. Near the trail between Lubuagan and Sicician, in the sandy shale portions of what must be the same general formation, I found the following, which stamp the formation as Miocene: *Turbo borneensis* Bttg., *Pecten senatorius* K. Mart., *Pecten leopardus* K. Mart., *Cardium* sp., *Conus* sp., *Fungia decipiens* (K. Mart.), *Cassidaria* sp.,

Tapis sp., *Dosinia* sp., *Turbinella tjidamarensis* K. Mart., and fragments of *Alcyonaria.*

Shales.—The shales that are found intercalated with the sandstone of this region grade imperceptibly into it. Mineralogically they are the same; they differ merely in grain size. Plate 20, fig. 1, gives an excellent idea of their field occurrence. The frequent alternation of sandy and shaly layers in practically all of the sections seen shows that these beds were laid down in shallow water.

Conglomerates.—I have already alluded to a local conglomerate associated with the limestone at Sagada, but the one referred to here is the conglomerate formerly thought to be equivalent to the Agno beds of von Drasche. The formation is not so well developed as in the type locality on Agno River. These are well exposed in the lower Bued Cañon. The formation is, mineralogically, the same as the sandstone and the shale, the difference being again one of grain size with the "grains" the size of bowlders. Naturally, andesite and diorite predominate, as those rocks predominated in the ancient headlands of the Tertiary seas. It is very easy to confuse some of the volcanic agglomerate with these conglomerates. Also, the sandstones in places simulate conglomerates, due to the concentric weathering of the thicker, bedded layers.

Sinter.—In this region there are occasional hot springs where there are great quantities of siliceous and calcareous sinter. This condition can be seen at Mainit, near Bontoc.

Travertine.—A complete list of sedimentaries must include the ubiquitous stream deposit known as travertine, which is found here and there in the streams, usually indicating the presence of a limestone remnant somewhere above on the crest of the mountains. As pointed out, in other parts of the Philippines this deposit is found most abundantly on shale and, when it occurs, it completely obliterates the rock beneath.

A rather remarkable physiographic feature of the Benguet country is Trinidad Valley, a roughly circular, flat-bottomed area about 1.5 kilometers in diameter, partially surrounded by coral limestone of Malumbang age, and dipping about 15° to 20° west. The presence of coral fragments in great profusion in some places, especially in Trinidad Gap, and the generally circular outline caused von Drasche to call this an elevated atoll. Recent field studies by Dickerson and myself cause us seriously to question this explanation. We believe that this is purely an

erosion phenomenon. A detailed discussion of this appears in a paper by Dickerson.*

THE CAGAYAN BASIN

The Cagayan basin is a long valley of varying width lying between the Cordillera Central and the Sierra Madre Mountains of northeastern Luzon. In places the alluvial plain is narrow, due to low spurs from the cordilleras. The valley is underlain in large part by the formations of the Batan and Vigo groups (middle Miocene) beneath a varying thickness of alluvium which is added to each year by the river floods. Ferguson investigated some coal deposits in this valley, near Alcala, which proved to be of inferior quality.(266)

Whether the valley is a broad synclinal or a rift valley I am unable to say, since I have done no work in that region, but the topography seems to indicate the former rather than the latter.†

Cagayan River with its large tributary, the Chico, meanders in wide sweeps through grassland, tobacco fields, and forest land. This is one of the most important agricultural districts of the Archipelago. The largest tobacco plantations are located chiefly in this valley.

THE EASTERN CORDILLERA

The eastern cordillera has a general north and south trend, but is marked by some sinuosities, following pretty closely the east coast of Luzon; so that in its southern extension, where it cuts through Camarines Sur, particularly in the Caramoan Peninsula, it trends almost east and west. Very little is known about the eastern cordillera, and but few prospectors have crossed it. Here and there in the northern part some adventurous ones, notably Heise and Dudley, crossed. Ickis made a reconnaissance from Laguna de Bay to Infanta,(336) and Pratt and Adams made reconnaissances on Caramoan Peninsula.(497) A few boats have skirted the east coast of Luzon, but very

* Philip. Journ. Sci. 23 (1923) 437.

† This interpretation has recently been confirmed by Dr. A. N. Kryshtafovich, who made a rapid survey of this valley. Professor Koto, of the Imperial University, Tokyo, Japan, has suggested to me that this valley is a rift valley and is a continuation of the great rift which he has found on the eastern margin of Formosa. It seems that Koto is mistaken, for it appears to be more probable that the continuation of the Formosan rift is southward, close to the western coast of Luzon, as indicated by soundings in those waters.

fragmentary observations have been recorded. According to all reports the eastern cordillera, in the northern portion at least, is close to the sea and is steep cliffed, which would indicate recent elevation. Here follow a few notes made by Eddingfield, during a trip in 1913 by boat around the east coast.

The coast northeast and east of Cagua is sedimentary. These sediments extend from the northernmost point of Luzon southward for at least 45 kilometers. Northeast of Cagua they appear to strike northwest and southeast and dip about 70° northeast. They make up an irregular sawtooth range of hills with very precipitous slopes. Numerous caves are visible from the steamer. Farther south the dip varies to the east as if constantly dipping away from Cagua. Here too sharp peaks are characteristic of the sediments. The next 50 kilometers of the coast were indeterminate as the steamer was too far from shore.

The rocks at Ports Dimalansan and Bicobian, north of Palanan Bay, are igneous. They are for the most part coarsely crystalline pyroxenites which in places are rather schistose in appearance. They are cut by several dikes of fine-grained rock. Igneous rock probably extends inland at least as far as Mounts Cresta and Moises. At Palanan Point limestones appear and extend southward along the coast. At Disumangit Point the limestones are much twisted and stand nearly vertical, striking approximately north and south. One cliff of limestone was made up of alternating, narrow, light and dark bands, very much twisted, giving a curly or wavy appearance. These limestones probably extend as far as Dilasag Bay. The hills behind are probably igneous intrusives which produced the folding, as in the case of Cagua Volcano.

The rocks surrounding Casiguran Sound are igneous, diorite, andesite, and pyroxenite, and probably extend for 12 to 20 kilometers inland to a band of sedimentaries which pass northward through Bulacan and Nueva Ecija. These sediments probably extend at least as far as Pugo near which limestone is reported. Governor Grove, of Nueva Vizcaya, reported that near Pugo, Gonip River, which flows into the Conwop, a branch of the Cagayan, flows for a considerable distance under a mountain of sediments. It is possible that this band extends the entire length of Luzon as is the case on the west coast.

Gold is marked on d'Almonte's map as being found in the mountains opposite Cape Ildefonso, but its existence at the present time is apparently unknown. The Ilongots and Negritos never have any gold, although the former are great metal workers and are very fond of ornaments. They apparently do no mining but obtain silver and brass from the towns to make their ornaments. However, there probably is a body of iron ore near here for the compass is affected by something in this section.

East of Baler is an outcrop of coarsely crystalline pyroxenite similar to that found at Palanan Bay. Information obtained from prospectors shows that these igneous rocks extend south at least as far as Mount Angelo. This corresponds to and joins the section made by Ickis across the eastern cordillera which extends the igneous to Atimonan.

There are several good ports on the east coast of Luzon, Port Lampon, Dingalan Bay, Casiguran Sound, Port Bicobian, Port Dimalansan. The coast north of Dimalansan is bad landing on account of the coral reefs.

This section is practically uninhabited except for a few scattered Negrito houses. At Palanan is a small Negrito town. Baler and Casiguran are fair-sized towns in which one or two Americans live; between these are several small Negrito towns.

It is needless to say that we know very little about the elevation of this cordillera, except that it is much lower than the central cordillera.*

We know practically nothing about the formations in the northern part of this range. Ferguson visited a volcanic peak, Mount Cagua, near the northernmost point. Semper (547) found periodite in the Sierra Madres, as the northern part of the eastern cordillera is known. Ickis made a cross-section from Tanay to Infanta (fig. 6) through the central part, showing closely folded sediments, with diorite and andesites. Adams and Pratt found andesite in the part of the range in Camarines Sur, and schist areas in the Caramoan Peninsula.

For our knowledge of the central portion of this cordillera we are indebted to McCaskey, Dalburg, Pratt, and Smith. It is a region of closely folded sedimentaries and crystalline rocks (fig. 7). This region is sparsely settled, mainly by remontados and Negritos, as one would expect from the rugged nature of the topography.

The principal stream draining this portion of the country is the Angat, one of the wildest and most picturesque to be found in the Philippines. The damming of this stream some 10 to 15 kilometers above Norzagaray is contemplated by the Metropolitan Water District of Manila, the purpose being to secure a greater water supply for Manila; at the same time, abundant and cheap power will be secured.

The map indicating the distribution of civilized and wild peoples,† shows that the whole eastern cordillera, from Cape Engaño to Casigu-

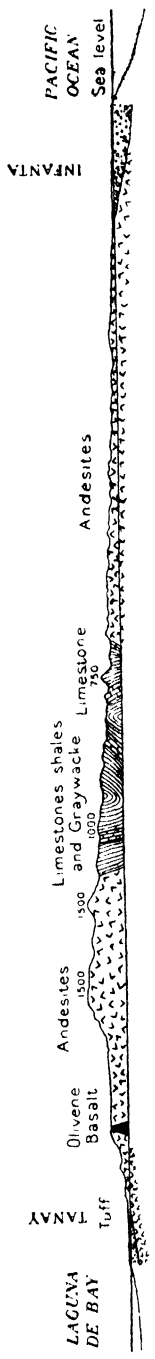


FIG. 6. General geologic section across Luzon, from Infanta to Tanay.

* United States Army aviators who have recently flown over the region report some peaks, estimated as at least 3,000 meters high.

† First Philippine Census 2 (1903).

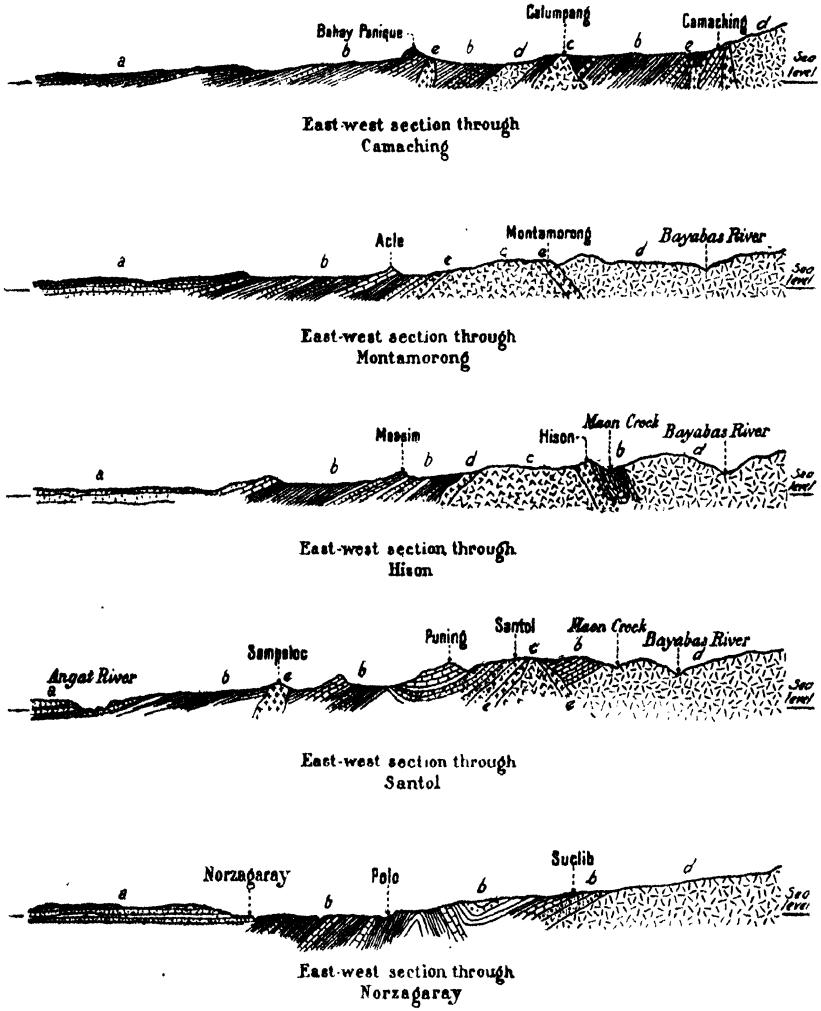


FIG. 7. Geologic sections through the iron-ore region of Bulacan, diagrammatic in part; *a*, post-Miocene sediments; *b*, Miocene sediments; *c*, granite; *d*, effusives with intrusives; *e*, intrusives with effusives.

ran Bay and, except for two or three spots, as far south as Infanta, is inhabited by Negritos. Continuing along the coast almost to San Miguel Bay, there is a long strip pretty well taken up by Tagalogs. Then, in the Caramoan Peninsula, Negritos are found again, with some Bicols. On the whole, the population is very sparse.

Beginning at the north, we find several well-defined passes through this range, and these passes mark the location of trails leading from the interior to the coast. The first one connects the headwaters of Ilagan River and Palanan Bay. About 80 kilometers south there is another, between the headwaters of Cagayan River and Casiguran Bay. Only a few kilometers south of that is a pass between Cabanatuan and Baler. This is perhaps the most important pass in eastern Luzon, separating two considerable massifs of the eastern cordillera. This pass affords also a break-through for typhoons. The next important pass follows Chico River from Peñaranda to Dingalan Bay. Farther south is the route followed by Ickis from Tanay on Laguna de Bay to Infanta. Another one extends from Pagsanjan to Mauban, thence from Lucena to Atimonan.

In Camarines Sur the cordillera splits into two parts; the one following the Caramoan Peninsula, as already described, the other stretching in a southeasterly direction into Sorsogon. The latter is crossed in two very important places, one trail leading from Naga (Nueva Caceres) to Pasacao, and the other from Albay to Pilar. These passes have been very important factors in the settlement of certain parts of the east coast. There has always been very little trading along the east coast. Several isolated spots are occupied by Tagalogs. It is my opinion that these Tagalogs have come across the mountains by way of the passes noted above rather than by the longer way of the sea. From what we know of the history of the United States, and in fact all countries, mountains are great control factors in the distribution of people.†

THE SOUTHWESTERN VOLCANIC REGION

This region is fully described by Adams(21) in a paper on the geology of southwestern Luzon. It comprises, roughly, Rizal, Cavite, Laguna, and Batangas Provinces and a portion of northwestern Tayabas Province. It includes within its area such prominent physiographic features as Taal Volcano, which was destructively active in 1911; several extinct cones, Banahao, Maquiling, etc.; several small crater lakes near San Pablo; the very interesting lakes, Bay and Taal; and Pasig River.

† An especially pertinent example is the Cumberland Gap leading from the Appalachian valleys into the "blue grass" regions of Kentucky and Tennessee. During a certain period practically the entire flow of the population westward was through this pass.

As one would expect, this region is underlain with volcanic materials of one kind or another, andesitic lava, agglomerate, and tuffs. Other formations appear on the edge of the Manila coastal plain, such as river aluvium near rivers, conglomerates and sandstones near the coast, and limestones, shales, etc., of Miocene Tertiary on the inner margin, near the eastern cordillera.

Formerly there was a much greater extension of the sea inland, probably as far east as the eastern rim of Laguna de Bay; later this was cut off, and a much larger lake than the present one undoubtedly existed. By the filling in of pyroclastic material, accompanied by elevation, the former connection with the sea was broken.

The recent elevation of this country is remarkably well shown on the southern coast of Batangas, where terraces over 50 meters high and with several steps can be seen from a passing vessel. Running through this country are several sharply defined fault lines which have influenced the topography to a marked extent. One of these is the now well-known Taal Volcano line first pointed out by Pratt. A fuller discussion of this is given in the chapter on Seismology. Another well-marked line is defined by the prominent scarp trending north and south, just east of Laguna de Bay. Still another marked topographic feature is the escarpment just west of Montalban Gorge, about 40 kilometers northeast of Manila.

Manila is located on the low saturated alluvium just bordering the great tuff area which is extensively developed to the eastward.

No economic mineral product other than sand, gravel, and stone for construction purposes comes from this region. Some years ago attempts to make cement on Binangonan Peninsula were unsuccessful.

THE SOUTHEASTERN VOLCANIC REGION

In northwestern Camarines Sur the mountain ranges diverge, undoubtedly belonging to different systems, one fork running through Caramoan Peninsula, and the other following the west coast. Between these two, on what was originally a more or less level plain, there has been built up a cluster of volcanic cones more or less dissected by erosion. However, one of these, Mount Mayon, is probably the most nearly perfect volcanic cone in the world (Plate 29). This is the highest of the group, and is only a short distance from Legaspi. What must have been a larger cone is now represented by Mount Isarog, but the sym-

metry of this has been destroyed by the sliding out of one side of the crater. In spite of the great size of these mountains and the deep cañons on their slopes, they are of very recent origin. Adams, who made a trip through that country, compiled the various reports in an interesting and able discussion.(21)

Of all the travelers through this district, Charles Martin has brought back the best photographic records. In 1909 Martin and a Franciscan priest from Tabaco made an ascent of Mount Mayon, and secured fine pictures of the crater and of the country as seen from the summit.

Farther south, in Sorsogon, is another large, somewhat dissected volcanic stock called Mount Bulusan. This is much like Mount Isarog in general appearance.

West of this cluster of volcanic mountains lies the beautiful Bicol plain, which is probably an old trough filled partly with river alluvium and partly with volcanic ejecta. According to Dr. A. N. Kryshtafovich, there is a prominent fault line on the west side of this plain where the valley fill abuts on the folded rocks in the low cordillera which follows down the west side of this peninsula.

THE CARAMOAN PENINSULA

This prominent peninsula, east of San Miguel Bay, is a continuation of the metamorphic region of the well-known gold district of Paracale and Mambulao. According to Pratt the rocks in this region are dominantly schistose.(497)

THE CENTRAL KNOT

This complex of mountain ranges, formed by the coalescing of the Cordillera Central and the Caraballo Sur Mountains, is situated largely in Nueva Vizcaya Province. No geologic work has been done in this region by Government geologists since the time of the Spanish geologist Abella. This able investigator studied the region in 1881, particularly the areas bordering the igneous masses of that area, in connection with earthquake studies. According to one cross section in his report, which followed the highway from San Jose in Nueva Ecija to Solano in Nueva Vizcaya (that is, from south to north across the divide of the Caraballo Sur Mountains), there are folded Tertiary sediments, conglomerates, sandstones, and shales abutting on diorite. To the south these sediments are overlain by the tuffs and alluvium of the central plain. Abella seems to have realized the importance of a study of faults in connection with the subject,

but he makes little mention of any in his descriptions. He concludes that the earthquakes of that region were of little importance.

The Philippine Government is now building a first-class macadam highway which will pass through the heart of this region, connecting the central plain with Cagayan Valley.

There is no mining activity in this region, but guano and phosphate rock are being mined at a locality a few kilometers east of Tuguegarao.

THE INTERMEDIATE UPLANDS

All of the territory that is not coastal plain or central plain, and is not above 1,500 meters in elevation, will be designated the intermediate uplands. Topographically, it consists of the foothills and the sloping flanks of the high cordilleras. The rocks may be of all classes, but the chief formations are the folded Tertiary sediments, limestones, sandstones, and shales, with the coal seams (where they exist) sloping away from the central ranges. The lower, and generally worn-down, volcanic stocks will also be included under this heading.

In the western part of northern Luzon there is a series of hills, lower than the ranges that make up the cordilleras, with a linear north and south arrangement, between which lie comparatively flat reaches occupied by streams of varying size. Across these cut larger and stronger streams, clearly antecedent, which have maintained their courses across the ranges or ridges as these were thrust up in their paths. In part these low parallel ranges are due to folding, in part to faulting. The most important and striking examples of these antecedent streams is the Abra, which reaches the sea through a great water gap near Vigan, Ilocos Sur (Plate 19, fig. 1).

Some of this topography, in La Union Province particularly, may be said to approach "Cuesta" topography; that is, alternating belts of ridges and flat areas of softer rocks.

The population in the intermediate uplands consists largely of the less-progressive types. In certain parts of Luzon, such as Batangas and Laguna Provinces, where the underlying formation is a decomposing volcanic material and where the country is not too greatly dissected by streams, there is a fairly prosperous population; but in the uplands of northern Luzon very little advancement could be noted until after 1900. There are few roads, and there is comparatively little communication between the settlements. The greater dissection of the country by the

streams has decreased the area of agricultural land, and unless the mineral resources be developed the country will always remain comparatively backward.

SUMMARY OF THE GEOLOGY OF LUZON

If we examine the general geologic map of Luzon, we distinguish in the southern part a rough lining up of formations into belts having a northwest and southeast trend, as follows:

1. At the extreme southeast, there is a zone of metamorphic rocks beginning on the small island of Rapurapu and extending northward through Camarines Sur, especially in Caramoan Peninsula. The continuation of these rocks has been picked up in the eastern cordillera, farther north.

2. Next to the westward is a belt of recent volcanics. In this belt are the well-known cones of Bulusan, Mayon, Iriga, Isarog, and the almost worn-down stock of Bagacay.

3. The narrow Albay plain, composed of tuffs and alluvium.

4. A broader belt of folded Tertiary sediments in the western part of Sorsogon Peninsula, constituting practically the whole of Tayabas Peninsula. Bondoc Peninsula, with its folded and faulted sandstones, shales, and oil seeps, belongs in this belt. The belt continues into central Luzon, where it becomes partially concealed by later volcanic flows.

5. There is another volcanic zone, which takes in Taal, Maquiling, Banahao, etc., at the eastern edge of the central plain.

6. The plain belt, beginning with the Cavite plain and the central plain, extending north to Lingayen Gulf. The extinct volcanic cone Arayat, near the center, is the commanding feature of this plain.

7. The line of andesite stocks constituting the Zambales. Plutonic rocks, diorites, and gabbros, as well as schists and argillites, were found by von Drasche and by Abella in this region. The superstructure, however, is andesitic.

8. Westernmost are the basic and dense rocks of the Cinco Picos Range, just west of Subig Bay. This formation is really almost insignificant in area, but it is very important.

In the northern part such clean-cut separations cannot be made, owing largely to lack of knowledge. However, a rough parallelism of belts can be made out.

The eastern cordillera is made up of intensely folded Tertiary sediments—crystalline rocks, granitics, and schists and, later, lava and agglomerate flows. In northern Luzon there is one

solfataric volcano, Mount Cagua. With this exception no volcano, either active or extinct, is known in the whole belt.

In the region of Cagayan Valley there is a vast area of folded Tertiary rocks, principally sandstones and shales. The geology of the great backbone of Luzon, the Cordillera Central, is discussed under the head of the Mountain Province.

West of this central "ridgepole" there is the Malaya Range consisting again of old volcanic flows, intrusives, and folded sediments.

The stratigraphic column is essentially that of the Archipelago as a whole. The reader is referred to the table and remarks in the chapter on Stratigraphy.

ECONOMIC MINERALS

A great many economic minerals have been discovered on Luzon, among others gold, copper, iron, platinum, galena, antimony, molybdenite, coal, asbestos, manganese, sulphur, and salt. Only gold, copper, iron, and salt have been economically exploited. To-day the only production in Luzon comes from one quartz mine in Benguet, one gold dredge in the Paracale district, and some crude iron furnaces in Bulacan Province. On Batan Island there are two producing coal mines, but their present production is small. The mines and mineral deposits are described in the chapter on Economic Geology.

MARINDUQUE

Goodman is the only Bureau of Science geologist who has made a study of Marinduque Island. Considerable prospecting and development work has been carried on by Manila people without any production. The status of the lead prospects on this island will be found in the chapter on Economic Geology.

The following is from a manuscript report, 1907, by Goodman:

> Marinduque is approximately circular in outline and covers an area of about 350 square miles. It is situated between the coast of Luzon, which partly encircles it on the north and east, and Mindoro, which lies about 25 miles west of it. Marinduque now belongs under the jurisdiction of Tayabas, its independent provincial government having been abolished in November, 1902.
>
> A mountain range, which traverses the island in a general north and south direction, constitutes the core of the island and divides it into two nearly equal parts. It is fairly uniform in altitude and approximates 1,600 feet above the level of the sea, although a few of the peaks, such as Marlanga, Gazan, and San Antonio, rise about 500 to 700 feet above the general profile. The western slope of the mountain range is rather steep and thickly bedecked with timber, while the eastern slope is in general

more gentle and covered with grass. In fact, a large part of eastern Marinduque is given up to pasture and stock raising, for which purposes it is eminently adapted.

Transportation about the island is mainly by sea, the principal towns being located on, or very near, the coast. The only wagon road in the island is about 23.5 miles long, and extends along the west coast from the barrio of Mogpog, about 4 miles north of Boac, to the barrio of Buena Vista, about 8 miles south of Gazan.* Agriculture is the main pursuit of the inhabitants, and the cultivation of rice, hemp, and coconuts is carried on over almost the entire island.

Marinduque is built upon a foundation of igneous rocks, chiefly diorite (in some places quartz diorite) and andesite. It is quite possible that the latter is but a superficial phase of the former, its porphyritic texture being due to the more-rapid cooling of the igneous mass. These basal rocks were covered with a series of sedimentaries, of which a very siliceous white sandstone was the most important member. The period of sedimentation was probably followed by one of eruptive activity, which produced a blanket deposit of tuff and andesite, and this was in its turn submerged to be covered with a capping of white limestone. Then came the final elevating thrust, which being applied either unequally or to an unequally yielding mass, caused a prevailing dip of the overlying strata southward.

The eruptive period in the island's history witnessed not only a considerable change in the topography but also a marked alteration and metamorphism of the earlier rocks. The white sandstone became a fine-grained white quartzite, while the igneous rock suffered a change both in composition and in structure. In some places, notably in the southwestern part of the island, are immense serpentine and chloritic outcrops which resulted from the alteration of the most basic igneous rocks. These rocks have in places become so squeezed and shattered as a result of metamorphic process, as to cause them to take on a fine felsitic texture, and to develop a marked cleavage structure. Numerous fissures were also opened during this period, to become filled in time from quartz and ore-bearing solutions. One of these is about 7 miles east of Boac on the bank of Malaquing Sapa, in the barrio of Tapiing. Here there is a 15-inch fissure vein of slightly auriferous quartz between igneous walls, one of which is the dark felsite much fractured and the other a quartz diorite containing considerable pyrite.

From the direction of the fissures and the strike of the folded strata, it seems likely that the direction of the dynamic stresses was approximately north-northeast and south-southwest. The fissure veins in igneous rocks show no remarkable uniformity in strike and were probably first caused by contraction of the molten mass to be later modified by rock movements.

About three-fourths of a mile west-northwest of the barrio of Masolokot, intersecting Pansui Creek, which here runs almost due east, is an outcrop of a quartz lode. On the north side of the creek is a hard quartz vein, 10 to 12 feet wide, running approximately north-northwest and south-

* Since 1907 another road, from Santa Cruz to Torrejos, has been constructed.—W. D. S.

southeast and dipping about 35° west-southwest. The outcrop has been exposed by erosion for about 50 feet, but scarcely any development work has been done upon it by the locators. The country rock is a fractured andesite, and the main cleavage plane is roughly parallel to the plane of the vein. The contact is quite distinct but irregular, and large "horses" of the country rock are inclosed in the vein itself. Stringers or lenses of galena also appear in the matrix, most of them being small. The largest, which consists of practically pure galena and a very small amount of iron pyrites, has been followed for about 12 feet, in which distance it has widened from about 2 to 10 inches. The chute appears to be lenticular in form, dipping downward along the strike as well as lying parallel to the vein itself. The vein is very irregular in mineralization, and samples taken from different portions of the vein show it to be surprisingly poor in gold and silver values.

On the south side of the river the lode splits into two branches, making an angle of nearly 180° with each other.

A much more promising prospect is the one near the barrio of Pacascasan. Here Mr. C. J. Cooke has located and staked a claim on a quartz vein, which at the time of my visit was entirely undeveloped with the exception of a small open cut across the vein and about 4 feet deep. This exposes a 5-foot vein of red clay and honeycombed and crystallized quartz, containing a small amount of galena and pyrite. A small amount of free gold was also observed in the quartz. From the small area uncovered and from other outcrops, the strike of the vein appears to be northwest and southeast with a slight dip toward the southwest, but other outcrops near the discovery line suggest that there is more than one vein or that these outcrops belong to offshoots from the original vein. Both walls of the vein are andesite, which has been very much kaolinized and stained at the contact, making the line of demarcation indistinct.

The location of the prospect is admirably adapted for economic operation. It is about 550 feet above sea level in a small draw and about 120 feet below the top of a ridge. This ridge is fairly steep and terminates in a coastal plain about 1.5 miles wide. What appears to be a well-protected port is in plain view about 2.5 miles distant.

In addition to the several lodes described, it is interesting and may prove of value to some, to report that in Napo River, about 300 yards south of the municipality of Santa Cruz, large and almost pure specimens of galena and chalcocite float were found. While no one specimen contained both minerals, it is quite possible that they were derived from, and constituted separate stringers in, the same vein. Some of the bowlders that contained both quartz and chalcocite weighed about 250 pounds and were nearly 2 feet in diameter. One of these specimens showed roughly 18 per cent copper, and 0.2 ounce gold and 8 ounces silver per ton. A rounded bowlder weighing about 10 pounds consisted of practically pure galena and carried 0.04 ounce gold and 6.85 ounces silver per ton. Unfortunately, the lode from which these specimens were derived could not be readily located, and it was impracticable to institute extensive explorations for that purpose, but it is almost certain to prove a valuable find to the successful prospector. It should not be very difficult to locate the lode, for the carrying power of the stream and the size and weight of the specimens indicate that the source cannot be far distant. Another sug-

gestive clue is the fact that the float was found in a low river bank, the base of which is igneous while the hill immediately above it is the hard white quartzite. It is therefore quite possible that the lode, like the float, will be found at the contact between the two formations of a vein.

Only one other mineral deposit was encountered of sufficient extent to be worth recording. This is a deposit of specular hematite which outcrops in the gorge of Maculapnit Sapa, a branch of Boac River. The deposit is about 20 feet thick and dips at an angle of 22° toward the southeast. It lies upon a floor of altered sandstone containing olivine, hematite, and secondary quartz, and is capped by a stratum of hard greenish impure quartzite, very much fractured and containing considerable pyrite. The extent of the deposit could not be definitely determined on account of the soil and vegetation which covered the ground, but to a height of 100 feet above the river, the ore could be easily traced. While there may be no objection to it on the score of quantity, the matters of quality and accessibility are less satisfactory. An analysis of a sample taken from the outcrop showed the following percentages: Iron, 56.88; SiO_2, 13.91; sulphur, 0.79; P, trace. The high percentage of sulphur is almost prohibitive, but this objection may be partly overcome by sorting, for the pyrite is not uniformly distributed through the ore, but occurs more or less in bunches.

There are several deposits of bat guano in Marinduque. As in other parts of the Philippines, they are located in caves of the limestone capping. One of the largest of these is located at an elevation of about 1,400 feet, in a place called Bongoy, about 3 miles north-northeast of the barrio of Duyai. This barrio is connected with the coast by a fairly good road, but from Duyai to the cave the ascent is steep and difficult. The mouth of the cave is wide and high, and its sides and roof are hung with large varicolored stalactites. The entrance is down a steep and rocky path to the cave proper, which is about 50 feet below. The main chamber is about 120 feet long by about 35 feet wide, and branching from it are three smaller chambers. The floors of all the chambers are covered with bat guano, which is wet and muddy at the center, but dry at the sides and ends. The average of several soundings showed but 2 feet of depth. It is estimated that there are about 400 tons of guano in this cave.

Another occurrence of geologic interest rather than economic importance, was observed about 2.5 miles up the stream from the barrio of Jabionan. Here a small flow of natural gas is emitted from a minute fissure in a metamorphosed igneous rock, composed largely of serpentine. This formation overlies a series of sedimentaries consisting mainly of impure limestones, and the latter are probably the source of the natural gas. Several other small gas leaks were noticed, some on the bottom of the stream and some on the banks, but all issued at a very low pressure. The largest of them afforded a flame but 7 inches high.

Whoever may be interested is cautioned that these notes are the results of observations for less than a month over an island of approximately 350 square miles. The work was, therefore, in the nature of a rapid reconnaissance, and the geologic inferences drawn as the result of hasty observations must be left subject to modification, should a more detailed study render it necessary. However, these notes may not be entirely without value to future prospectors, and even to the geologist these brief notes on an

island, which has to the writer's knowledge no other geologic literature, may perhaps be of some interest.

THE VISAYAN ISLANDS

The Visayan Islands constitute the middle portion of the Archipelago between Luzon and Mindanao. Mindoro is included in the Cuyo-Palawan group.

TABLE 9.—*The principal islands in the Visayan group in the order of size.*

	Square kilometers.
Samar	13,271
Negros	13,699
Panay	11,520
Leyte	7,249
Cebu	4,390
Bohol	3,973
Masbate	3,250

Samar, though the largest, is the least developed. It has the distinction also of being the rainiest part of the Archipelago.

Negros is one of the most fertile members of the group, the soil being largely volcanic. It is famous for its large sugar plantations.

Panay gives, perhaps, the greatest promise of substantial, all-round development of any. Sugar and rice are the main crops of this island. It has modern railroad facilities.

Leyte occupies an intermediate position, being neither very advanced nor very backward in development. It has no railroads, and the few large towns are on the coast. Abacá is the principal product. In the north are some bituminous sandstone deposits which are being exploited.

Cebu is the most populous island of the Philippine Archipelago. It has a modern railroad and bids fair, on account of its coal deposits, its geographic position, and its labor supply, to become the manufacturing center of the Philippines. On account of its rugged interior it is not foremost agriculturally. It has perhaps the best health conditions of the group.*

Bohol is an agricultural island with little modern development.

* Latest hookworm surveys show a high infestation average, perhaps above 70 per cent. One of the reasons given for this high average is the physiographic condition of the island.—V. E.

Masbate is best known for its gold mines, in the Aroroy district in the northern part. The interior offers a great range for livestock.

The population of the Visayas, as would be expected in a region of great coast line where the land masses are separated by short stretches of water, is largely seafaring and more closely united than is the case in other parts of the Archipelago, where great mountain chains act as formidable barriers to intercommunication. There are slight differences from island to island, but the population is essentially a unit throughout the group.*

SAMAR

Becker confines his remarks on Samar to one paragraph, in which he refers to coal. He did not visit the island.

Adams(17) is the only geologist, to my knowledge, who has written anything about this island prior to 1921, and he touched at only one or two points near Catbalogan.

Hubert G. Schenck made a six weeks' reconnaissance on Samar in company with G. B. Moody, a geologist in the employ of one of the large oil companies exploring the Islands.

GEOLOGY OF SAMAR †

No geologic survey of Samar Island had been attempted until the fall of 1920, when a party consisting of G. B. Moody and H. G. Schenck entered the field. Mr. Moody, chief of the party, was engaged upon economic work, while Mr. Schenck was detailed to accompany him. The island lies between the parallels 11° 01′ and 12° 36′ north latitude and the meridians 124° 15′ and 125° 46′ east longitude; in shape, it may be considered as a large trapezium, about 12,000 square kilometers in area. Less than 240 kilometers of roads have been built, and reliable maps of the entire island are few.

The physiography of Samar is in many ways unlike such islands as Luzon. Nearly all of Samar Province is maturely dissected; the igneous area is limited in extent, while limestone is abundant. Rivers, shallow and rocky, are extremely numerous, making water communication a difficult matter. Outcrops are more abundant along the coasts, where they are not so effectively hidden by vegetation as in the interior. There is no great "Cordillera Central" on Samar, with the result that a large amount of rain is evenly distributed over the entire island.

In studying the rocks of the island, the writer was surprised to note some of the features of the sediments; many of the rocks were puzzling.

* Beyer recognizes four subdialects; namely, Cebu, Aklan, Panay, and Samar-Leyte.

† Résumé of a paper by Hubert G. Schenck, Philip. Journ. Sci. 20 (1922) 231.

In the center of the island, in the bed of Ulot River, a specimen of a peculiar rock was collected, which was called a quartzite in the field and even under the hand lens it seemed to be that metamorphic rock; but a thin section shows that it is a feldspar porphyry. Another rock that caused much discussion in the field and in the laboratory came from the Wright-Taft trail, east of the barrio of Bagakay. It shows under the microscope together with other minerals angular to rounded crystals of plagioclase feldspar, all of which are fractured, and some show marked evidences of having undergone strain; so that this specimen may be an igneous rock that has undergone so much metamorphosing action that to-day it resembles a clastic rock. The most surprising relationship of all, however, was that of *Lepidocyclina* in angular and subangular fragments of limestone with rounded igneous pebbles; formations which in the field were thought to be Miocene in age were shown to be post-Miocene and thus definitely established an unconformity between the Miocene and the Pliocene. The sandstone formations of Samar are typically feldspathic, and point to a diorite as the probable basement complex of the island.

As to structure, not enough definite information was obtained during the reconnaissance to work out in any detail the broad structural relationships. The data now in hand indicate an island with an igneous core, some monoclinal strata, minor folds, much faulting, an unconformity after the Vigo (Miocene), a topographic unconformity between the Pleistocene and the Recent formations, and complex earth movements. The last-named feature is worthy of consideration, in so far as some evidence supports a theory of differential tilting of Samar, while there is as good evidence supporting a theory of general marine terracing of the entire island. Major faults parallel the seismotectonic line on the west coast and the Philippine deep on the Pacific side.

The party found no important economic metallic minerals on Samar; though they were told fabulous tales of rich deposits, strange to say, no specimens were brought forth to support the stories. The coal is too "young" to be of much value, and the beds are faulted; it was probably deposited in local basins, at times during torrential rains, and it would not be at all surprising if the beds thicken and thin to some degree; so that the coal of Samar, in addition to being of poor grade, is geologically unfavorable for development. It is not likely that Samar will ever become a large producer of minerals, though of course, further prospecting may bring to light minerals which are more accessible and perhaps capable of being mined commercially.

Roth describes the rocks and formations observed by Jagor during his trip through portions of Samar.*

NEGROS

Previous to my visit to Negros in the spring of 1922 very little geologic data on this island existed. The Spanish geologists seem to have passed it by. Becker(50) has a few scattered notes, but owing to the politically disturbed condition of the country

* Roth's description was translated by Schenck, Philip. Journ. Sci. 20 (1922) 263.

in 1900 he was unable to go far inland. He went ashore at one or two points on Negros during the insurrection, in 1900, for very short excursions. He found the stream pebbles for the most part andesitic. On page 556 of his report(50) he refers to the strike and folding of the coal measures as follows:

In the Island of Negros, the folding of the lignitic series has been similar to that in Cebu. The predominant rock of this series along the Talabe River is sandstone, which is accompanied by shales and some limestone. The whole series is considerably indurated. The strata are much distorted and faulted. The strike is usually to the east of north, or nearly in the direction of the axis of the volcanic range. The dips are from 30° to 70° or more, and it is clear that the coral reef formation, which is continuous for some miles from the coast, rests on the upturned edges of the lignitic series.

On page 572, he devotes a paragraph to the coal outcrops on Talabe River, but evidently he was not much impressed by their commercial possibilities. He states:

In the northeastern portion of Negros coal seams occur, lying 6 or 8 miles from the coast and in a line substantially parallel with it. They are exposed in the channels of the rivers Talabe, Calatrava (or Macasilao), and Luzón. It is said that some of the seams are of good width and quality. I visited that on the Talabe, but found nothing of value. Two seams were exposed; neither had over a foot of fuel, and they carried pyrite. The lignite was jet black, and seemed to belong to the same class as the Cebú lignites. The seams lay between walls of bituminous shale and dipped 30° NW. The stratification in the neighborhood was much disturbed. There were many pieces of float coal in the river, and very possibly there are other seams hereabout, but the natives professed to know of no other exposure. It was my intention to explore the entire belt of deposits, but an attack on my escort by a relatively large body of natives put an end to prospecting. This belt is well worth examination when the natives quiet down. Governor Larena also informed me of a coal deposit in southwestern Negros, to the eastward of Cabancalan. Efforts to obtain detailed information failed.

Negros is situated between 9° 4′ and 11° 1′ north latitude and between 122° 24′ and 123° 34′ east longitude. It is 200 kilometers long and in its widest portion about 90 kilometers wide.

TOPOGRAPHY

Most of Negros is mountainous, and a considerable portion, though not the greater, consists of volcanic mountains. The northwestern portion, where most of the sugar is raised, is of volcanic origin; but the entire eastern strip and a large part of the southern part of the island consist of folded and faulted Tertiary sediments, plutonic rocks, slates, and jaspers of prob-

able Mesozoic age, and some Tertiary extrusives, all more or less dissected and worn down by erosion. Topographically and geologically, Negros can be divided into two parts.

The northwestern portion consists of an extensive coastal plain, the largest and richest in the Philippines, which flanks a line of older and younger volcanoes, of which Mount Canlaon is the highest and most recently active (1904). Between the coastal plain and the volcanic mountains there is a wide strip of country made up largely of gently sloping terrane formed by the wash of ash and bowlders from the volcanoes. These great alluvial fans are deeply dissected by the torrential streams that come from the heights above. This part of Negros is of extremely recent origin, and its formation is almost the last episode in the history of the island.

The other part of Negros, while not so high as the volcanic part, is more rugged and consists of greatly eroded, folded, and faulted mountains in the extreme eastern portion, while in some of the southern portion erosion has proceeded to such an extent that the relief is moderate. Therefore, the true cordillera and "grain" of the island run northeast and southwest and close to the east coast for the most part, while the line of volcanoes in the northern portion is a later and superficial feature of the island.

In spite of the latter statement and from the human point of view, the dominant features of Negros are: First, the extensive coastal plain, from 10 to 30 kilometers in width, affording perhaps the richest strip of agricultural land in the Philippines; and, second, the majestic, though not perfectly symmetrical, cone of Mount Canlaon rising from this plain to an elevation of 2,438 meters.

The mountains in the eastern part rarely exceed 1,000 meters in height; but the proximity of these to the coast, in some places only 2 to 3 kilometers distant, exaggerates their height. Furthermore, the streams of the east coast are short and swift; consequently, the effect of erosion is more pronounced and gorges and cataracts are the rule.

A feature of the topography of Negros of vital importance to the sugar industry of the island is the following: The line of volcanic mountains in the northern part is not continuous, and between the several volcanoes there are comparatively low (200 to 300 meters) areas which allow the moisture-laden winds to break through the barrier and give a more-uniform precipitation throughout the year. The north and south sky line of

the island, as seen from a boat aproaching the west coast, will help to clarify some of the foregoing statements. The principal peaks along this sky line, beginning at the north, are Lantauan, 1,049 meters; Silay, 1,534 meters; Mandalagan, 1,880 meters; Canlaon, 2,438 meters; and, in the extreme south, Cuernos de Negros (the horns of Negros).

A generalized east and west profile is shown in the idealized geologic section in fig. 8.

A noteworthy feature of the volcanic-plain topography in Negros is the incised meanders of the streams. In the lower portion of these streams where the declivity had become almost zero, and consequently the velocity of the streams is likewise low, the serpentine curves of old-age topography, or those characteristic of most streams at grade, had been developed. Later, when the latest episode in the geologic history of Negros oc-

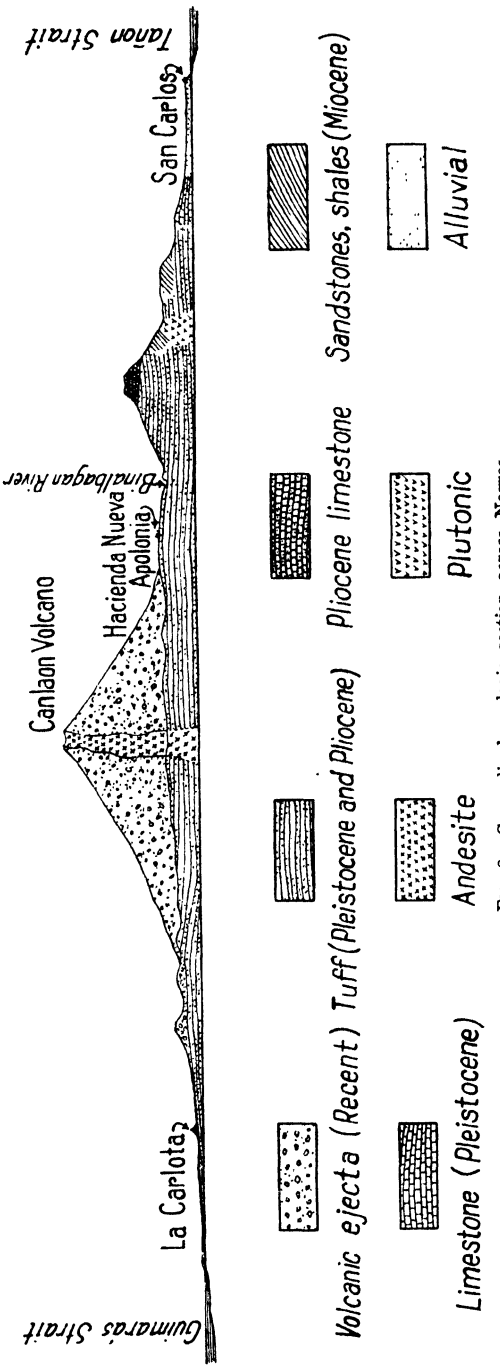


FIG. 8. Generalized geologic section across Negros.

curred, these streams, due to the marked uplift of the island, amounting in the northwestern portion to at least 10 meters, began to take on new life and cut downward, thus incising these meanders, so that they are a striking feature of the topography in the middle portion of the plain.

In summarizing, we may speak of the topography of western Negros as youthful, with long gentle parabolic curves as the rule; while that of eastern Negros is youthful also, but is of the faulted mountain type of which straighter lines and serrated sky lines are the characteristic features. In southern Negros, on the other hand, a maturer topography than that of the above-mentioned portions is found.

HYDROGRAPHY

The hydrography of Negros embraces a consideration of the ocean and harbors, the rivers and lakes, and the ground water.

OCEAN AND HARBORS

Negros is surrounded on the east by the exceedingly deep Tañon Strait, on the north by Jinotolo Channel, on the south and west by Panay Sea. The soundings on the Coast and Geodetic Survey charts show shallow water on the west, particularly between Guimaras and Negros, the maximum depth between Panay and Negros being 18 fathoms, while in Tañon Strait 297 fathoms have been noted.

Although Negros has approximately 600 kilometers of coast line there are few good natural harbors in the entire length, and those in localities of no utility at present—at Escalante on the northeast coast and at Campomanes Bay on the southwest coast. At San Carlos on the coast, at about 10° 30′, there is a fairly good harbor where, even in typhoons, ocean-going vessels can lie at the pier. At Bais fair anchorage can be counted on in the southwest-monsoon season. On the west coast there is the possibility (at Pulupandan particularly), if breakwaters are constructed, of securing a very good harbor, though at considerable expense. It is on the west coast, where most of the sugar is produced, that a harbor is essential. On the south coast there are some indentations that are either small or have no important back country, and they may be dismissed for the present.

The lack of harbors on Negros is directly due to the geology of the island. This island has been rising during recent times, and under such conditions indentations suitable for harbors are rare. Contrast the coast line of Negros with that of northern

Palawan, for instance, which has numerous large and small indentations, all due to recent submergence and the consequent drowning of the lower portions of river valleys.

RIVERS AND LAKES

Most of the rivers of Negros are unnavigable for the same general reason that there are no good harbors. The principal river is the Danao, which debouches near Escalante and which, while not very long, is navigable for vessels of light draft for several kilometers. Other rivers of importance are the Binalbagan, the Bago, and the Ilog, which will permit the entrance of flat-bottomed lorchas for 5 to 10 kilometers and are navigable for dugout canoes for much longer distances, in some cases one or two days' travel. The periodic overflowing of these rivers has added greatly to the value of the sugar land in the lower courses of the rivers.

Binalbagan River is the longest, as it rises on the eastern flanks of Canlaon, at first flowing southeast, then within one-half day's march of the coast, about 10 kilometers, it is turned sharply south by the wall of the coast range and swings southwest and west, finally reaching the sea on the west side of the island. On the flanks of Canlaon this river is a roaring torrent, clear and cold; at Binalbagan it is wide, fairly deep, sluggish, and full of silt.

Bago River rises in the saddle between Mount Mandalagan and Mount Canlaon and flows to the sea some distance south of Bacolod. The run-off of this river, as gauged by the Bureau of Public Works, shows tremendous fluctuations with the seasons. For example, as low as 212,200 second liters were recorded in November, 1920, while in September of the same year nearly 8,000,000 second liters were recorded. In July, 1921, as high as 18,000,000 second liters were registered. Similar data are not available for the other rivers.

Ilog River rises in the foot of the boot of Negros near the heel and flows northwesterly into the sea south of Panay. Perhaps the finest sugar land in Negros is located along its lower course. One important branch of Ilog River is known as the Tablas, since it rises in a moderately elevated table-land near the heart of the lower end of the island.

Besides these rivers there are numerous shorter streams, the shortest being on the east coast, for reasons already given.

Owing to the heavy growth of timber about the headwaters of most of these streams, in the later volcanic and older mountains of Tertiary age, the run-off of the streams is better con-

trolled than if the mountains were bare, even though in the lower courses the country is quite without vegetation of a kind to act as a check on the run-off of the precipitation, and to this is largely due the fact that floods of destructive violence are not frequent. In fact, I was informed by local residents that Ilog River had very rarely reached extreme flood conditions previous to 1919. A moderate amount of flooding, such as is often experienced in the region of Kabankalan, is of great benefit in adding new silt to the soil. Judging by soil analyses and cane production, this region is one of the best on the west side of the island.

GROUND WATER

As the bulk of western Negros, where the sugar production is concentrated, is of volcanic formation, consisting of more or less tuff (consolidated volcanic ash) overlain by loose volcanic sand and bowlders, the ordinary river banks do not show sections deep enough to enable one to get any idea except by inference as to the deeper-lying formations. The deepest river cut noted was about 25 meters in the upper Bago River, but well logs made from stratification samples collected by the Bureau of Public Works will help materially in supplying information on that point (Table 10).

It will be noted that (*a*) there is great difference between the logs of wells on the east coast and those on the western side of the island. The former penetrate sedimentary formations, while the latter pass, almost without exception, through volcanic ejecta; (*b*) there is little regularity in the succession of strata in the volcanic material; (*c*) water can be found at almost any depth in the volcanic plain; (*d*) the water has, generally, to be pumped; that is to say, true artesian conditions do not exist; (*e*) the water in the wells on the east coast is harder than on the other side, except in the southwest (where the same conditions exist) due to the penetration of limestone on the eastern side. An exception exists in one well at San Carlos, which has a very dark colored and soft water, very fine for boiler purposes. This well evidently drains a buried swamp.

The surface of the water table, for the present at least, lies pretty close to the present surface of the land, depressed here and there by deep gorges in the volcanic plain where most of the wells are located. There should be little trouble in securing water anywhere on this plain at reasonable depths for a long time to come, but no accurate predictions as to depth or quantity can be made.

TABLE 10.—*Showing well logs from borings made by the Bureau of Public Works in Negros.*

Depth.	Locality.			
	Binalbagan.	Cadiz.	Escalante	Bais.
Feet.				
20	Sand, gravel, and clay.	Silt and shells.	Coarse white coral sand.	Gray calcareous clay.
40	Black pebbly clay.		Yellow clay with limestone pebbles.	Do.
60	Black sticky clay.		White calcareous clay.	
80	do.	Silt and shells.	Coarse calcareous sand.	
100	do.		do.	Yellow calcareous clay with coral and shell.
120	do.		do.	Do.
140	Gray andesitic gravel.		do.	Do.
160	Fine gray feldspar sand.	Fine sea sand.	do.	Do.
180	Medium gray feldspar sand.		White marl.	Coarse coralline limestone sand.
200	Yellow argillaceous sand.		Coarse calcareous sand.	Do.
220	Yellow pebbly clay.		do.	Mixed igneous and calcareous sand.
240	Black carbonaceous clay.		White marl.	Black carbonaceous and calcareous clay.
260	Coarse andesitic clay.		do.	Do.
280	Coarse andesitic sand with shells.		do.	Do.
300	Medium gray andesitic sand.		do.	Do.
320	Fine gray andesitic sand.		Coral limestone.	Coarse coralline limestone sand.
340	do.		Gray shale.	Do.
360	Coarse gray andesitic sand.		Gray doby.	
450			do.	
790			do.	

On the lower portions of the western plain of Negros the water is so close to the surface that in regions of adobe soil the land needs drainage badly. Some of the water is, of course, surface water, but a great deal of it is ground water.

By digging shallow cisterns surface seepage water can be obtained almost anywhere in northwestern Negros in sufficient quantities for all ordinary purposes. Furthermore, sufficient water for irrigating the higher ground or for use during ex-

ceptionally dry seasons can, by means of diversion weirs, be taken from the many streams that cross this plain.

CLIMATE

Walker, formerly of the Bureau of Science, worked in Negros in 1909 when there was no meteorologic station on that island; but within the past few years, attendant upon the rapid erection of modern sugar centrals, observers have been placed on this island by the Weather Bureau, and complete data of this nature are available. I am indebted to Father Miguel Selga, S. J., assistant director of the Weather Bureau, who personally established these stations, for Table 11.

The chief point I wish to bring out here is that the topography of Negros is such that a very variable rainfall is the result. At the north end of the volcanic range, at Cadiz, Manapla, etc., the rainfall is abundant and well distributed, since the moisture from both the northeast trade wind and the southwest cyclonic winds is precipitated in this region. Likewise, at Murcia, just opposite the great gap due to the low saddle between Mount Mandalagan and Canlaon, the rainfall is in great contrast to that recorded at points in the lee of either of those two great masses. This was particularly notable during December, 1921, when the weather station at Murcia recorded 465.9 millimeters, while the nearest figure to that is 191.2 millimeters at Silay. During the same period only 49.8 millimeters were recorded at San Jose, which is well protected behind Canlaon, on the southwest slope.

SETTLEMENTS AND LINES OF COMMUNICATION

The principal towns of Negros are Dumaguete, the capital of Oriental Negros, and Bacolod, the capital of Occidental Negros. There is no city or port of the first class on the island, and in this respect Negros is far behind some of the less-productive islands of the Archipelago.

Practically all the settlements of importance are located on or close to the coast, or along the indefinite line marking the junction between the littoral and the alluvial fans on the flanks of the volcanic mountains or of the coastal plain and the folded Tertiary mountains. There is no road across the island from one side to the other, though one is under construction by way of Binalbagan Valley. The location of towns and lines of communication is influenced by the physiographic features of the island. The effect of mountain barriers is best shown

TABLE 11.—*Monthly and annual rainfall in millimeters for 1921, at Weather Bureau stations in Negros.*

Station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total.	
Tanhay	42 6	195.4	105.4	14 5	118 6	77.5	374.4				465 2	56 6		
Palanas	112 8	132 1	95 4	0 0	156 8	195 7	349 9	111 3		353 5	321.6	119 5		
Bais	68 4	50 7	57 2		336.5		428 0	122 0				165.2		
Vallehermoso	200.0	51 0	73 2	73 4	111 8	97 3	144.9	133.6	110.9	339 3	224 8	102 4	1,662 6	
Hacienda Refugio	133 7	65 2	73 9	40 6	197.5	118 2	88.9	124 2	215.8	177.0	266.0	102.6	1,603 1	
San Carlos	145 9	67 7	65 3	45 7	145.5	152 4	71 1	103 8	170.2	216 2	281.2	130.6	1,595 6	
Cadiz	117 4	135 3	108 2	23 1	118.1	141 0	208 6	174 3	166.5	352.8	442.0	134.5	2,121.8	
Hacienda Bilbao	313 1	141 2	190 0	93 5	81 0	158 8	228 9	43.6	175.1	413 8	667.8	161.3	2,614.1	
Hacienda Ylaya	166 6	161 8	200 5	145 5	110 4	222 4	401 8	166.5	235.9	670.8	760 8	147.7	3,390.7	
Central Victorias					136 2	339 8	484 2	214 7		743 1	1,156 8	173.8		
Hawaiian-Philippine Sugar Co	264 1	110 6	144 7	180 5	83.8	383 0	243 3	182 1	286.5	530 2	1,103.1	160.3	3,672 2	
Silay	193 9	83 6	125 8	133 7	21 3	275 9	218.1	139 5	254 9	451.1	880.5	191.2	2,969.5	
Bacolod	83 4	42 5	99 1	22 2	130 1	262 4	298 8	228 5	188.8	183 4	552.1	109.7	2,201 0	
Murcia	50.9	50 7	41 3	26 3	174.0	384.4	322 4	182 7	242.6	103 6	374 6	465.9	2,419 4	
Santa Cecilia	16.5	52 9	68 8	86 4	316 4	221 0	459.7	245 8	176.9	268 6	479 5	57.0	2,449 5	
La Granja	56 5	123 1	53 8	121 1	241 1	304 9	558 0	339.5	413 1	339 7	496 1	74.2	3,121.1	
Central Azucarera de la Carlota	75 7	116 8	53 8	126 8	214 2	212 4	533.2	289 8	390.6	239.0	469 7	98 8	2,820 8	
Hacienda Canlaon	62 0	86 9	50 2	58 0	232 1	194 8	645 4	232 1	194 8	69.0	176 8	50.2	2,052 3	
La Castellana	60 2	62 4	49.1	72 8	185 1	212 4	546 5	281 7	392 8	311 2	466 6	110.4	2,751 2	
Isabela	95 5	87 6	24 1	25 7	191 5	294 5	605.2	235 6	355 7	332.6	328.8	114.3	2,691 1	
Hacienda Tanolo	56 5	102 0	74 3	667 2	157 2	132.7	520 1	309 8	342 8	136 2	326.5	34.2	2,259.5	
Binalbagan Estate	26 3	114 5	61 8	106 3	190 6	221 1	485 6	304 1	319.9	213 3	328 8	83 9	2,456 0	
Hacienda Naval					60 2	271 9	207.3	573 9	260 5	357.7	240.5	329.5	106 7	
Central Palma	18 7				53 3	190 5	158 6	317 0	16 6		67 0	195 9	138 2	

by the fact that in Oriental Negros the dialect is Cebuan Visayan and in Occidental Negros Panayan Visayan is spoken.

GEOLOGY

In fig. 8 I have attempted to give a generalized cross section of Negros Island as it appeared to me in crossing from La Carlota on the western side to Vallehermoso on the east coast. This section is not drawn to an exact scale, but is approximately correct.

To ascertain the nature of the formations of Negros, one must go to the eastern part, the narrow strip of Tertiary cordillera, which is older than the western part. "Float" in the streams will indicate what is hidden in the mountains, for this includes fragments of slate, jasper, and deep-seated plutonic rocks very similar to those in other islands of the group. Since it is generally the rule in geology to begin with the older rocks and ascend the geologic column the cordillera west of Vallehermoso should be considered first. There are found sediments, sandstone, and shales tilted at high angles and stratigraphically below (though above topographically) the coast limestone; below these Miocene strata are still older, though not always visible, Mesozoic (?) slate and jaspers. These have been seen as yet only in one or two localities as "float." Cutting the last and pushing up under the Tertiary beds are larger and smaller intrusions of granitic rocks, diorite or gabbro, which are igneous, but not of volcanic origin. Above all of these stratigraphically (in some cases below and in others above topographically) are hundreds (in such masses as Canlaon and Silay, thousands) of meters of tuff, loose ash, and bowlders of andesite and basalt. Last of all come the alluvial deposits and raised beaches of the Recent period. These are about the lowest topographically, yet the highest in the stratigraphic column.

The chief point to grasp at the outset, before the geology of Negros can be understood, is that the larger part of western Negros is young, superficial, and totally different from the eastern part, which is much older. In fact, western Negros is merely a late episode in the history of the island. First there was a small, narrow island mass along the eastern edge of the present island, or there may have been a land mass where Tañon Strait is now, though this was doubtless later. From these older masses erosion removed much, if not most, of the terrane and deposited it as sand and lime close to shore, and as mud in the deeper water; later, these became sandstone, limestone,

and shale, respectively. The sandstone eventually became quartzite; the limestone, marble; and the shale, slate.* This was in the Mesozoic or earlier. After this came strenuous mountain-making movements with intrusions of igneous rock. Subsequent erosion and, still later, blanketing by other deposits have obscured most of this early history. Erosion and slow sinking of the land accounted for the accumulation of additional hundreds of meters of sediments. These were subsequently hoisted through further mountain-making movements, and folded and faulted. Previous to this there may have been land connection with Cebu; later, through down-folding and faulting, the sea encroached so as to cover the sunken area.

As before, just as soon as the land emerged from the sea, erosion began its inevitable work of leveling the folds. As this work proceeded there was another subsidence, and a great mantle of coral limestone was laid down over the upturned Tertiary strata, thus marking an unconformity.

Again, the tremendous forces of Nature raised the rocks of Negros to great heights, and remains of this limestone formation are found on the summits of some of the highest points of the eastern mountains. This formation is called the Malumbang, because it was first described, and perhaps best developed, on the Malumbang plain of Bondoc Peninsula, Tayabas Province, southeastern Luzon. This limestone belongs to the Pliocene period in the geologic column. The lime dissolved out of this by the rain and the streams makes the soils of eastern Negros richer than those of northwestern Negros. The greater percentage of phosphorus pentoxide (P_2O_5) in the eastern soils and in certain soils of the southwestern portion is undoubtedly due to the leaching of guano in the caves of the same formation.

The high potash content shown by the analyses of soils of Bais and San Carlos made by Walker † may be explained by the presence of orthoclase feldspar and possibly leucite, not yet noted in the igneous rocks, in the nature of intrusions in the eastern cordillera of this region. In my hasty examination of this region igneous rocks were noted, but no detailed studies could be made at the time.

Up to this time the western shore line of Negros was not very far from the present east coast. Probably the coast line and plain were similar to the east coast and plain of to-day. Then,

* I have not found all of these in Negros.

† The Sugar Industry in the Island of Negros. Manila (1910). 68.

perhaps suddenly, or perhaps more slowly, those tremendous eruptions began which resulted in the great piles of volcanic ejecta, Mounts Mandalagan, Silay, Canlaon, and others. There was not the quiet welling up of lava, as is known to have been the case in the Hawaiian Islands, but there were terrific explosive outpourings of ash and bowlders. They began in the Piocene and continued intermittently to the present time; and so, partly by the fall of volcanic ejecta, partly by the work of streams, and partly by the work of shore currents, that magnificent plain of Occidental Negros, the great sugar region of the Philippines, perhaps the richest coastal plain in the Archipelago, was built up.

The last episode in the history of Negros was the elevation within very recent times of the western part at least, and maybe of the whole, amounting to nearly 30 meters. This is indicated by the raised beaches near Pontevedra, the bluffs of Bacolod, and the incised meanders in the streams of the volcanic and littoral plains.

CANLAON VOLCANO *

The active volcano of Canlaon, or Malaspina, and the numerous thermal springs of Negros are interesting geologic or geographic features. This cone (Plate 32) is the highest of a series of volcanic elevations; it is 2,438 meters in height, and is constantly sending forth sulphurous vapors and other gases. The ascent is best made from Maso on the west slope, and during the northeast monsoon when the weather is always dry and extremely agreeable.

Canlaon consists of two cones: an older extinct one having a maximum height of 2,200 meters, partially filled to a level of 300 meters below the rim with lava, ash, and sand, and on the floor of which there is a small lake of alkaline water, more or less permanent; and another, higher, active cone which has erupted just outside the south rim of the older and debouched a large amount of material into the older or north crater, its north side extending for a considerable distance into the older crater. The east and west slopes of the newer crater consist of exposed tuff, lava, ash, and sand, with a considerable admixture of volcanic bombs (biscuits?) and the western slope is much serried by deep crevices due to washing of torrential rains. The same condition obtains on the north slope, into the old crater. The

* This description of Canlaon Volcano is contributed by Charles S. Banks.

south slope of the new cone is at first precipitous, then it rather gradually merges into the main axis of the range with no high peaks salient. On the east slope of the old and the new craters are many fumaroles, three lying south-southeast of the new cone, almost always conspicuous by their vapor emanations.

The descent into the old crater is best made at its southwest corner, where the explorer is aided by the north slope of the new crater, which continues to the floor of the old. Ella Pass, at the northwest corner of the old crater, makes access possible but rather difficult. It was through this pass that the first American expedition gained entrance to the old crater in Easter week of 1902, when I organized a party which was financed by Mr. Juan Araneta, of Maao, who was a member of the party. Five American teachers were also members, and seventy Filipinos served as helpers, cargadores, and guides.

There are large deposits of sulphur visible within the active crater of Canlaon; but, owing to the continuous exhalation of vapors of sulphur dioxide (monoxide?) and to the great heat, they will probably never be worked. There are indications of deposits on the slopes of the mountain, and in the old crater there is much of this material half buried in the vegetation. The active cone of Canlaon is bare of plants for a distance of 300 to 500 meters down its sides; but the mossy forest lies less than 100 meters below the rim of the old crater, and vegetation, including sizable trees, lines the crater itself, except on its south side.

ECONOMIC GEOLOGY

The geologic products of economic importance in Negros, in the order of their present value to the denizens of that island, are: Water, soils, limestone, road metal, coal, sulphur, clays, and iron.

HOT SPRINGS.

There are two well-known hot springs in Negros and several of less importance. I visited the best known, Mambucal, which is situated on the northwestern slope of Canlaon Volcano at about 300 meters elevation. Hot water and steam issue from various vents in a deep ravine. The rocks all about are kaolinized and discolored with varicolored iron salts. There are some nipa shacks in the vicinity, but no improved bath arrangements.

The people use the water by tempering it with fresh cold water from the main creek. Many Filipinos travel from various

parts of Negros to make use of these waters, which are said to be especially efficacious against rheumatism. The next best known hot spring is Mambajao, near La Castellana, on the southwestern slope of Canlaon.

These hot waters are of course due to uncooled lava in the substructure of Canlaon Volcano. Such springs are common in volcanic regions and are subject to change, depending upon the subterranean conditions in such localities. The springs merit attention and improvement, and might well be used as sites for sanatoria; indeed, some such action is contemplated by the provincial authorities of Occidental Negros.

SOILS

In the parts of Negros visited by me the following principal types of soil were noted:

Residual clay; highland volcanic soil, much iron, almost a laterite; andesite subsoil; on recently logged-off land.—Cadiz.

Adobe, tuff subsoil.—Maao, Occidental Negros.

Residual soil; clay loam, impure; Tertiary sandstone and shale subsoil.—Ilog and Tablas Rivers, upper reaches and adjacent slopes.

Colluvial volcanic soil, volcanic bowlders; gravel and sand subsoil.—Bacolod and Murcia. Very patchy.

Transported clay, coastal.—Victorias and Silay.

Black volcanic sand; tuff subsoil.—Silay, elevation, about 90 to 150 meters. Poor, owing to lack of water and solubles.

Sandy loam; alluvial.—Bearin and La Palma, near Kabankalan. Very superior.

Clay loam.—Alluvial fans on slopes of Silay and other mountains, upland stretches east of Silay, elevation 150 to 300 meters.

Calcareous soils on east coast and in the south near Kabankalan, derived from limestone areas.

Sandy soils, close to sea margin. Poor for cane.

In my preliminary studies of the soils of Negros, I investigated the most diverse kinds in an attempt to show how many kinds there are and their origin.

Before discussing some of these particularly, the principal minerals found in the soils of Negros and something of their rôle in the development of agriculture on the island should be explained.

The soils of northwestern Negros come from volcanic rocks of the andesitic variety, and have as their principal minerals some glassy feldspars (sanidine), lime-soda feldspars (plagioclase), hornblende and angite (ferromagnesian minerals), magnetite (iron oxide), a small amount of quartz, volcanic glass,

limonite, various oxides of manganese, and clay. Limestones, carbonates, quartz, and potash minerals are relatively scarce.

In the limestone regions of the east coast and in the vicinity of Kabankalan lime carbonate and phosphates are relatively more abundant, but potash is still a negligible quantity for the reason that the rocks from which these soils are derived are deficient or entirely lacking in potash minerals.

One ingredient of the soil in certain localities, particularly in the railway cut about halfway between Murcia and Santa Rosa, was noteworthy. At that place there is a 25-centimeter bed of manganese nodules about 50 centimeters below the soil. These nodules are from 1 to 2.5 centimeters in diameter and are psilomelane (manganese oxide) concretions derived from the surrounding soil; their presence here in so concentrated a deposit suggests that the soil generally in western Negros must be high in manganese. If so, it is appropriate to raise and attempt to answer the questions: What is the rôle of manganese in the production of sugar cane? Does it benefit or do harm? Although some authorities are silent on these points, Hilgard has this to say:*

> A decided difference in the manganese content of the arid as against the humid soils appears in the table, the ratio being about 11:13 in favor of the humid soils. Manganese has not been regarded as being of special importance to plant growth in general, although, as already stated, some plants contain a relatively large proportion of manganese in their ashes; thus, e. g., the leaves of the long leaved pine of the cotton states. But no definite data showing the importance of this element to crops were available until Loew and his co-workers at Tokyo † established its stimulating action in a number of cases, in which crop production was materially increased by the use of protoxid salts of manganese.

Another investigator indicates that manganese stimulates the nodule-forming bacteria that fix nitrogen in the legumes.

As ferromagnesian minerals are very abundant in the soils of Negros, particularly in the volcanic areas, it should be stated that, unless present in excess, magnesia is beneficial; but Loew ‡ has shown that certain proportions of magnesia to lime must be preserved if production is to be satisfactory.

These chemical considerations might be followed up indefinitely, but a few words must be said about the physical condition of the soils, as this is of even greater importance than are the

* Soils, p. 383. Negros would be classed as a humid region.

† Bull. Agr. Coll. Tokyo 5 Nos. 2 and 4.

‡ Bull. Agr. Coll. Tokyo 4 No. 5.

chemical considerations. Without going deeply into the discussion, several important points relating to the physical condition of humid soils, in contrast to those of arid regions, will be briefly enumerated.

1. Sands in humid regions are less productive than those of arid regions. This is due to the effect of the rains washing the sand grains in the former clean of the soluble decomposition products and carrying them into the subsoil or into the surface drainage.

2. Hydrous silicates are more abundant in arid than in humid soils. These compounds, known as zeolites, are important in making certain refractory silicates available for plant use. Some of the older volcanic extrusive rocks in Negros show a notable amount of zeolites, and this is a favorable point.

3. Humid soils are poorer in potash than are arid soils. This is due to the solubility of potash salts.

4. Humid soils are, unless well drained, very prone to sourness, and to counteract this condition the remedies most frequently employed are drainage and neutralization with lime. The lime need not be in the form of calcium hydroxide, as finely crushed limestone will suffice.

5. According to Hilgard, humid soils contain more humus than do arid soils, and more nitrogen in the soil but less nitrogen in the humus.

6. While rock decomposition proceeds more rapidly in a humid tropical region like Negros than in the Temperate Zone, the depth of this rock decay is probably less in the former owing to the shallower penetration of ground water with carbon dioxide in solution.

The excellent discussion of the soils of Negros by Walker * should be read in this connection.

LIME AND PHOSPHATES

There is a great development of sedimentary rocks in Negros, and limestone is abundant in the eastern part and in the south near Kabankalan. Unfortunately, in the principal sugar district, northwestern Negros, limestone, and consequently lime in the soil, is lacking. The rôle of lime in agriculture is twofold; namely, it is an important plant food, and it serves to neutralize acid soils. Certain Negros soils, according to Walker's analyses and the testimony of the planters there, possess both charac-

* The Sugar Industry in the Island of Negros. Manila (1910) 68.

teristics. In the volcanic region just mentioned lime is badly needed for both purposes.

Northwestern Negros has the following four possible sources of lime: The limestone formations in the vicinity of Kabankalan, the shell beds near Pontevedra, Guimaras Island, and the central valley of Panay.

Lime used for purification in the manufacture of sugar must be very pure and must be burned with great care. The limestone near Kabankalan, in the hills along Ilog River, could with skillful burning be used for this purpose. The fact that the lime heretofore used from that region and from Guimaras has not been satisfactory is due chiefly to the crude methods of manufacture. The chief drawback to the Guimaras lime is said to be its high magnesia content. Walker shows as high as 8+ per cent, but from analyses I have had of this limestone I believe this is exceptional. However, the Recent and the Pleistocene limestones are generally low in magnesia, and these should be used. The magnesia content increases with dolomitization, and this condition is a result of age.

Although I found no phosphatic limestones on Negros I am confident that phospates, in the form either of guano or of phosphatic limestone, will be found, since soils on the eastern side of the island where limestone is more abundant show on analysis considerably higher phosphoric acid content than do the soils in the volcanic regions.

It is reported that large phosphatic limestone deposits exist in the central valley of Panay, but these have not been investigated by the Bureau of Science. It is very probable that such deposits do exist, and if they are as reported the sugar-cane industry of Negros can benefit to the extent of millions of pesos by their use.

ROAD BALLAST OR METAL

In the western and southern parts of Negros the principal rock is andesite, which when fresh makes a fair road metal. It is not so good as diabase, diorite, or limestone, but will serve well if it is not decomposed. The gravel scooped out of the lower reaches of the rivers is usually inferior, but the fresher material from the higher slopes makes excellent ballast for railroads and much better metal for macadam.

Limestone is much better and can be obtained at many places on the east coast and in the southwestern part. It makes a better top, or surfacing, material on account of its high cemen-

tation value, but is not very resistant to abrasion. The most important factor in road construction is the nature of the subsoil on which highways are constructed, and a limestone subsoil is always well drained. The loose ash and bowldery alluvial fans of the volcanic slopes are equally good or even better.

Near Pontevedra (barrio of Miranda), about midway on the west coast, there is a long raised beach, about 10 meters above mean tide and about 100 meters from the present shore line, which consists of a bed of shells and little else, at least 2 meters thick. This material, already pretty well broken, is being used with excellent results as a top dressing on the provincial road which parallels the coast in this region.

Between Miranda and Hinigaran the provincial road cuts through a series of low hills which extend southwest from Canlaon Volcano and consist of tuff in the lower portion, with great blocks and bowlders, some tons in weight, on top. Some of these are very close to basalt in composition. This would be a suitable place to locate a rock crusher, as fairly fresh rock could be obtained here.

COAL

Coal on Negros has long been known, particularly in Escalante near Calatreva on the northeast coast, and its existence in southern Negros has been reported.

Coal was discovered near Calatreva in 1874 by Mr. Diego de la Viña, jr.(113) He reported a 4-meter seam occurring in several outcrops. Nothing was ever done except to file on it. The last locators were Martin Buck and the late Joaquin Casanovas, in 1896, the year of the outbreak of the insurrection against Spain.

The coal from Escalante is a lignite and, according to Cox,(149) has the composition noted in Table 12.

TABLE 12.—*Composition of coal from Escalante, Negros.*

	Per cent.
Water	12.97
Volatile combustible matter	43.39
Fixed carbon	34.10
Ash	9.54
Sulphur	1.67

At Cadiz, on the extreme northern coast, a still poorer lignite has been reported, but not worked. Of course, these coal seams have not been opened, and it is more than probable that a better grade of coal can be located in these places.

As some of the sugar centrals are forced to import coal for fuel, owing to shortage of bagasse, this coal might in time find a market in Negros. At the present time the centrals at San Carlos and Bais, on the eastern coast, are using coal mined near Toledo, Cebu. As the Escalante seams are a continuation of the Toledo seams, there appears to be a good prospect of developing a mine near the former locality. A railroad was once projected and surveyed from Escalante around the western coast to Pulupandan; were this constructed, the development of the Escalante coal might pay.

SULPHUR

Sulphur deposits exist on the slopes of Mount Silay. Elicaño has visited these deposits and his description is inserted here. *

There are three different sulphur deposits, namely; the Malisbog, claimed by Mr. Gerardo Alunan; the one at Mount Azufre, claimed by a company called Los Valientes in which Senator Guanco, Mr. Ortega, Mr. Jalandoni, and others are interested; and the other one on the other side of Mount Azufre, also claimed by Mr. Gerardo Alunan. The Malisbog is about 29 kilometers from Silay, while the other two are about 36 kilometers from the town. All of them lie in areas southeast of Silay.

There is a good automobile road of 13 kilometers to Guimbalaon barrio; from this to Agho there is a cart road of 3 kilometers; from Agho to the deposits there are only trails, which in some places are dangerous to follow due to the steepness of the hills. The deposits are all solfataric in character. The sulphur is found around vents from which emanate gaseous and steam vapors, those near the craters or vents being pure. The deposit claimed by the Los Valientes does not exceed 1 hectare in area, though the area claimed is 64 hectares. The total available ore in this deposit will probably not exceed 300 tons. The other claims are still smaller than that of Los Valientes.

There is no production of sulphur in the Philippines at present, owing to lack of demand. In 1918 the price was 5 pesos per picul (127 pounds), approximately 80 pesos per ton; there were about 50 tons on hand in the bodegas at Silay, Negros. When the value of sulphur as a fertilizer becomes more widely known there will be a greater demand for it in the agricultural districts. Its use in the drying of copra ought also to afford an outlet for this mineral.

Although sulphur has been found by investigators to be of benefit on soils where alfalfa is grown, the effects upon sugar-cane soils are not known. These should be studied.

* Mineral Resources of the Philippine Islands for the years 1917 and 1918 (1920) 41.

CLAYS

While no particular search for clay deposits of commercial value was made, great quantities of an inferior clay, such as is abundant in the Archipelago, were noted, particularly in the alluvial flats at the lower edge of the volcanic slopes. This clay is of the common kind known as adobe; it is rich in iron and always burns red. It is suitable for the making of tile, brick, and common pottery. Where drainage of some of these low-lying lands is resorted to, as is necessary even now, the drain tile required can be made locally. Near the sugar central at Victorias I saw extensive beds of such clay that had been opened during the digging of some cisterns.

Owing to the general absence of granitic rocks in that part of Negros geologically explored, it can be safely stated that the chance of finding high-grade clay is remote.

IRON

Iron deposits have been reported as existing in Negros; I have seen nothing more than bog iron, which in some localities is forming at the present time. There is no geologic reason why deposits of iron should not exist.

PRECIOUS METALS

Owing to the minor development of deep-seated igneous rocks in Negros, one need not expect to find the precious metals in important amounts, and no deposits of value have been located, though some have been reported.

POWER

With the abundant and fairly evenly distributed rainfall and the high wooded mountains and consequent steep gradients, there is no shortage of water power. Owing to the loose nature of much of the superficial formations and the torrential wash I should advise against the building of dams; these are pretty generally in danger of washing out and always likely to silt up, so that in a few years they are rendered worthless. A safer plan is to build diversion weirs. While I have made no measurements, it can be confidently asserted that sufficient water power exists on Negros to electrify all the railroads and turn all the wheels of industry that are likely to be used for some time. Preliminary investigations along this line have been begun by the Bureau of Public Works.

SOUTHEASTERN NEGROS *

We may regard the southeastern tip of Negros as a sort of volcanic peninsula, cut off from the rest of the island by the valley of Tanjay River and the bay of Tolong and the river heading in the low divide between Tolong and Tanjay. This peninsula is highly volcanic and culminates in the lofty Cuernos de Negros, or horns of Negros. These are very high, sharp-pointed peaks among the mountains behind Dumaguete and dominate all that part of Negros. There is a very narrow and fertile coastal plain which reaches its maximum in the fertile sugar-cane fields about Bais and becomes narrower southward; at Bacong it is practically nonexistent. From here to Tolong the coast is rocky most of the way, there being only a few small valleys where level fertile land occurs, until at Tolong there is again a considerable expanse of tillable level land.

The horn of Negros rising behind Luzuriaga has been ascended a number of times. There are two sharp peaks, the more remote one being the higher. Its altitude as given upon the maps is approximately correct and, according to Dr. J. W. Chapman's aneroid, is a little more than 2,000 meters.

The prevailing country rock, where visible, seems to be andesite of varying coarseness which, when weathered, resembles tuff; but the structure shows plainly on freshly fractured surfaces.

In the gorge of Okoi River, a few kilometers from Dumaguete, are hot springs. Here the walls of the cañon are vertical in many places and strongly resemble the bedded, water-assorted conglomerates common in many river valleys; yet the rock is all purely volcanic. The rounded, apparently water-worn pebbles and bowlders could be seen very plainly embedded in the wall, though so high up as to be inaccessible, and seemed to be a tuff or volcanic mud flow in which older volcanic bowlders and gravels have been buried. The specimens obtained from bowlders and outcrops in the floor of this valley seem to be basaltic.

In the hills back of Bacong is a small solfatara, of no particular importance.

On the side of the horn facing Zamboanguita are the scars of a number of large landslides, due to earthquakes. The recent

* These notes on southeastern Negros are furnished by Albert C. Herre, of the Bureau of Science.

destructive earthquake in Cebu caused one very extensive landslide which destroyed caingin fields and swept away a man and a carabao plowing near the edge of a gulch. The man escaped without serious injury.

Lake Balinsasayao lies west of Dumaguete, and 18 kilometers from the coast, immediately behind a large truncated pyramid of andesite, which is a conspicuous landmark. The lake occupies an old crater of great depth, with walls rising precipitously to a height of from 100 to more than 800 meters above it. The lake is about 1.5 kilometers long and about 1 kilometer in breadth and has several bays.

It is separated by a narrow wall of andesite, varying from about 15 to more than 30 meters in height, from a much smaller and apparently deeper lake. The two lakes seem to occupy a large single crater divided by a partition into two pits of unequal size. According to local tradition the smaller lake is over 400 meters deep, the larger one about 375.

The lakes contain no fish native to their waters, but have many *dalag* (*Ophicephalus striatus* Bloch) which were planted in 1908 by the owners of the abacá plantations in the vicinity.

West of the lake are two very sharp peaks rising about 800 meters above it and behind them is another cuerno, or horn, which is of unknown height, but which is materially higher than the one near Luzuriaga; it has never been ascended.

Three or four small, spring-fed rivulets pour into the lake, but the main source of its water supply is rain. The lake lies at an altitude of 1,000 meters, as measured by aneroid.

There is no outlet to the lake, and it is a typical alpine crater lake. That its level is being profoundly altered from time to time is, however, attested by twofold evidence. The rocks where, up to two years ago, one formerly embarked, at the point where the lake is approached, are now submerged about 5 meters, and are 15 meters or more from the present shore line.

Next to the water line was a belt of tree ferns ranging in height up to 5 or 6 meters and occupying the strip almost to the entire exclusion of other woody plants. These tree ferns have been killed by the rise in the water and now but a few dead ones, partially or totally submerged, are to be seen. The water had been about two-thirds of a meter higher than it was at the time of my visit in March, 1922, as shown by the water marks on the shore-line vegetation.

The rainy season of 1920–1921 was one of very unusual rainfall and great cloudiness in southern Negros, and this rise in

the lake was undoubtedly the result of a great excess of precipitation over evaporation. Since tree ferns are very slow-growing plants and live for centuries, it is likewise evident that the water line was for a long time much lower than it is at present.

PANAY

Between 1886 and 1890 Enrique Abella y Casariego,(12) assisted by d'Almonte, carried on geologic investigations on Panay. The results of these investigations, published in Spanish, embrace detailed descriptions of the general geologic features of the country, including orography, hydrography, the altitudes of all the principal points, and several chapters dealing with the volcanic formations and their tufas. There are chapters dealing with sedimentary formations, particularly the Tertiary series, and with economic geology.

Maurice Goodman touched at a few points on Panay in the latter part of 1905, about fifteen years after Abella. Goodman stayed in Panay less than ten days, and aside from some excellent limestone he found little of commercial value.

In the summer of 1912 W. E. Pratt made a rapid reconnaissance for petroleum in the vicinity of Janiuay.

In December, 1912, I continued the work begun by Pratt. During the course of this work, which was confined to the country immediately northwest of the city of Iloilo, the following notes regarding the general and economic geology were made:

A description of the general geographic features of Panay Island with quotations from Abella's work * (which appears only in the Spanish language) is the following:

The Island of Panay which for its size, richness, and population is the most important of the Philippines after Luzon, is situated among the Visayas precisely in the center of the Archipelago.

The island has, roughly, a triangular shape.

The greatest lengths which can be taken from north to south and from east to west are, respectively, 168 and 119 kilometers. Its total area is 11,580 square kilometers, of which 4,547 comprise the district of Capiz; 2,472, that of Antique; and 4,561, that of Iloilo.

The population of Panay consists almost entirely of Visayans and approximates 671,550, according to the census of 1918.

Temperature, rainfall, and vegetation conditions of Panay are very much like those of Cebu Island.

In spite of what is generally believed there is noted in Panay only one Cordillera, in the true sense of the word, which runs almost from north to

* An unpublished translation of this important document was made by H. D. McCaskey. This translation can be consulted in the library of the Bureau of Science.—W. D. S.

south, separating the district, or government, of Antique from those of Capiz and Iloilo. This Cordillera lies much nearer to the western coast than to the eastern and follows a sinuous course, starting in the extreme northwest corner of the Island, winding to the eastward, and then swinging back to the southwest corner. In the northeastern part of the island is a mountainous cluster but no true Cordillera exists although plutonic rock occurs there. Between these two is considerable flat country, but a little north of the center of the island is a highland tract connecting the western Cordillera and the eastern mountains.

North and south of this divide there is low country. The largest tract of plain country is comprised in what is called the central plain, the lower part of which is chiefly delta.

THE CENTRAL PLAIN OF PANAY

This important region is about 25 by 100 kilometers and lies between the main cordillera of Antique Province and the smaller eastern cordillera, in the extreme eastern part of the island. It is formed, as first pointed out by Abella, by the coalescing of two great alluvial fans of Panay River, which drains into Sibuyan Sea on the north, and that of Jalaur River, which debouches to the south into Iloilo Straits. These fans, following the simile of Abella, have their handles situated at Mount Baloy, the great central "knuckle" or knot of the island.

From personal examination of this region, I know that this alluvium is underlain at shallow depths by an extensive series of Tertiary shales and sandstones, which dip east from the main cordillera in a long monocline. Abella's work shows that the formations dip west from the eastern cordillera; therefore, this is an alluvial-filled synclinal valley.

A railroad runs the length of this valley, connecting the two important cities of Iloilo and Capiz. There is a low divide between the northern and the southern portions of this plain.

DISTRIBUTION OF THE POPULATION

Panay affords an excellent example of the influence of topography and geology upon the distribution of population. The three groups, Negritos, Bukidnons, and Visayans, are sharply defined and their distribution is controlled strictly by geologic and topographic factors. Where the rocks are hardest and most denuded of soil, where the topography is the most rugged, where existence is most difficult, there one finds the most-primitive people, the Negritos. The Bukidnons (or people of the mountains) occupy the intermediate uplands, across the divide between Capiz and Iloilo. They are the less-progressive Visayans who have had to give way before other more-energetic Filipinos.

Finally, the most-progressive inhabitants, the Visayans, occupy the lowlands.

VEGETATION

The island is remarkably free from forests, with the exception of a small area in the central portion of the cordillera. In this respect Panay resembles Cebu. The extreme deforestation is due to the caiñgin system, which consists of clearing and burning the forest on small tracts of land, raising a few crops on the hilly soil, and then abandoning the tract for a new location. This ruthless system is now showing its effects on the country. Without the retaining powers of the forest and undergrowth the rain water rapidly runs off, eroding the country and carrying enormous volumes of gravel and silt into the bottom land. This is the chief cause of the great devastation wrought by the streams in this and other parts of the Philippines. The sudden rise of mountain streams causes the water to pour out onto the plain, which results in great floods, ruined crops, destruction of bridges, etc., and in the rapid silting of river beds and filling of navigable streams, the formation of bars where once existed open channels, and other troublesome effects.

GENERAL GEOLOGY

As pointed out by Abella, the general classes of rocks found on Panay are the Recent formations of the plains; the Tertiary limestone, shales, and sandstone in the foothills; the core of igneous rocks in the cordillera; and some doubtful rocks, approaching slates, which lie between the older igneous rocks and the Tertiary series.

In many parts of the central plain there are remnants of raised reef limestones of post-Tertiary age which give evidence of the recent elevation of that region. Near Janiuay some of these are found nearly 200 meters in height.

The best development of sedimentaries (chiefly Tertiary) I have seen in the Philippines exists on Panay, and the best sections for studying them are perhaps to be found there.

Pratt estimated that the total thickness of the Tertiary series on Suague River amounts to more than 9,000 meters; if we include the older series of "slaty" rocks at the headwaters of Ulion River, the total is about 10,000 meters. As would be expected, I found much the same series on Tigum River. The two streams are roughly parallel and only a few kilometers apart. A short distance above the barrio of Tinayoo, the river

has cut into the hillside, affording an excellent section, which is typically as follows:

TABLE 13.—*Section on Tigum River.*

	Meters.
Thin-bedded sandy shale	15–20
Heavy-bedded sandstone	5
Sandstone	0.5
Carbonaceous shale	0.75
Sandstone	0.5
Carbonaceous shale	0.3
Heavy-bedded sandstone	5
Thin-bedded sandstone and shale	16
Heavy-bedded sandstone at base	?

The dip at this point is 30° southeast, and the strike north 10° east. A description of a typical sandstone from this section follows:

Sample 2312.—Buff to gray, very coarse, and apparently made up of the triturated particles from various kinds of igneous rocks occurring in the cordillera. There is little quartz in the specimen, but fragments of ferromagnesian minerals predominate. The buff color is largely due to fragments of olivine washed out of the decomposing picrites known to occur in the cordillera. This rock has a porosity of only 5.5 per cent; the voids are filled largely with iron oxide and calcium carbonate as a cementing material.

In the same series of sediments with these sandstone beds are several layers of conglomerate, conformable and of varying thickness. These conglomerates consist of many kinds of pebbles in a firmly cemented sandy matrix. At one place I noted pebbles and fragments of the following kinds of rocks: Limestone with coral remains, three or four varieties of andesite, amygdaloid, shale, rock resembling jasper but which is probably rhyolite as it appeared to have quartz phenocrysts, coarse-grained and fine-grained diorite, picrite, and quartz.

Occasionally, fossil shells are found, one of which is presumably *Vicarya callosa* Jenkins; this species indicates that the beds are middle Miocene, or of the same age as the Cebu coal measures.

SHALES

The shales exposed in the lower reaches of the streams flowing from the cordillera are thin-bedded and grayish to bluish, and they resemble Tertiary shales in many other parts of the Philippines; the type example is the Vigo shale on Bondoc

Peninsula, Tayabas, Luzon. These shales have practically the same mineral composition as the sandstone, the chief difference being in grain size. In the upper part of Tigum River the shales are yellowish, but lower they are bluish. In the survey of Tigum River I found that quite 5,000 meters of these shales are exposed, from the point where the survey began to the first considerable thickness of sandstone. Of course, there are occasional thin beds of sandstone in this series, but they are negligible. Several wells, drilled in these shales by the Bureau of Public Works in the hope of obtaining artesian water, have been generally unsuccessful. The water from these wells is salty, doubtless to be explained by the leaching of the soluble salts which were originally constituents of the marine deposits.

Rapidly changing conditions of sedimentation must have existed throughout the formation of these beds. The thinness of certain beds, the repeated alteration in character of the sediments, and the cross bedding indicate that there were either repeated oscillations of level or rapidly succeeding freshets, or both. It is important to note that the conditions are unfavorable for the formation of coal deposits of economic size. The only coal seams seen by me were not over 5 centimeters thick.

Structure.—The Tertiary series of shales and sandstones described above overlap the igneous core of the cordillera and constitute a great monocline dipping eastward toward the central plain. Near the cordillera the dip of the beds is as high as 70°, but gradually this inclination decreases till the beds assume an almost horizontal position. The inclination of the beds is much greater on the Antique (west) side of the cordillera. In the foothills local undulations with reverse dips attended by some faulting are to be noted. Abella's profiles and sections are representative of the general conditions.

The survey of Tigum River made by me revealed the existence of a small anticline just east of Maasin (fig. 9), and perhaps a detailed survey of the region would reveal others. These anticlines are all-important in the matter of the accumulation of oil. Complete folds in the strata are, however, the exception in this region, and the dominant structure is monoclinal.

PRE-TERTIARY FORMATIONS

At an elevation of about 400 meters near the headwaters of Ulion River I found an excellent exposure of indurated sediments closely resembling slate. Intercalated with these are sills of diorite, 3 to 5 meters thick. The sills followed the bed-

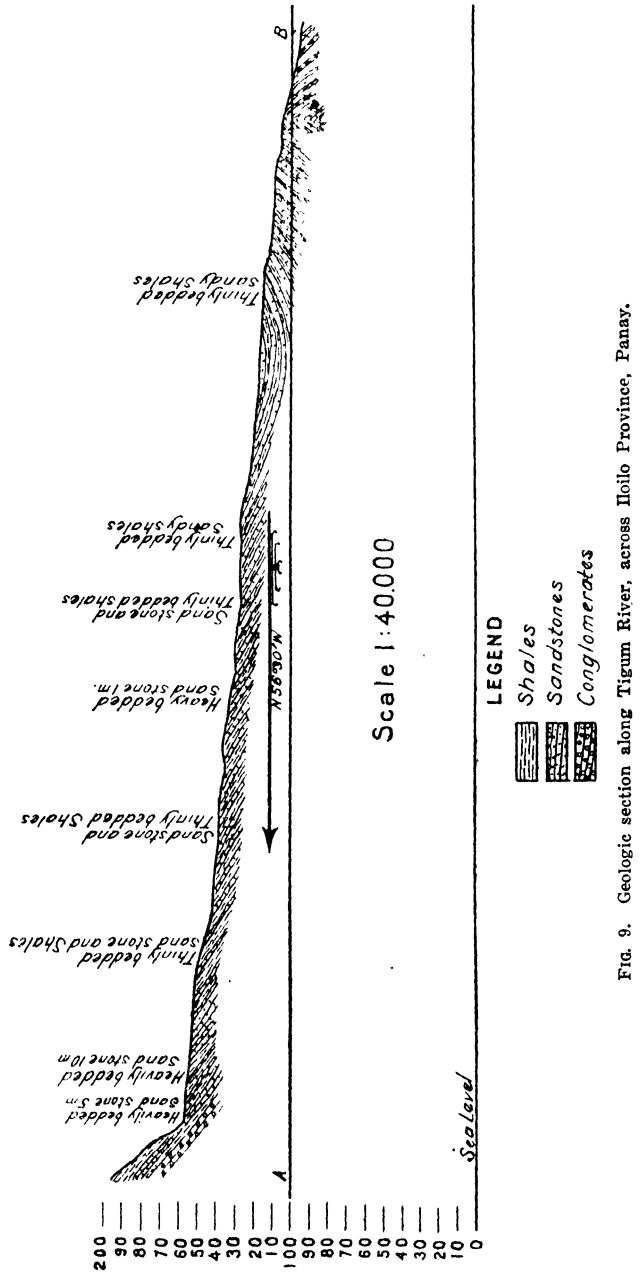


Fig. 9. Geologic section along Tigum River, across Iloilo Province, Panay.

ding planes. The strike of these slaty sediments is northwest and the dip 30° northeast. No marked difference was noted between that part of the sedimentary beds nearest the sills and

that in the interior; so it is improbable that the hard, slaty character of these beds can be due entirely to the heat or to pressure resulting from the intrusion of the sills.

Specimen 2322.—The rock is blue-black, very dense, exceedingly fine-grained, and has a hackly to conchoidal fracture. It shows on certain surfaces a very fine banding which is distinctly that of sedimentation. The parting in these beds is not typical slaty cleavage, and hence these are only pseudoslates.

Microscopic.—The thin section of this rock is difficult to study, because of the flakes of iron oxide and the numerous dark fragments which cannot be easily identified owing to their amorphous condition. Fragments of quartz, feldspar, and ferromagnesian minerals are abundant. The whole aspect of the section is that of a clastic rock. Numerous fragments of *Globigerina* and radiolarian tests are present, but neither the species nor the genera can be distinguished. This rock probably corresponds to the "clay slates" mentioned by Molengraaff in his descriptions of certain rocks collected in central Borneo, and to similar rocks in parts of the Philippines.

Molengraaff's descriptions are in fairly close agreement with what I found on the headwaters of Ulion River. The exact relationships in this rather confused group of rocks have not been determined; that we have in the Philippine Islands rocks practically identical with those of central Borneo and older than the Tertiary is important.

Near the source of Ulion River I found an outcrop of jasper, the position of which was not very clear; in thin sections this proved to be similar to that which I described from Ilocos Norte in 1906.

Sample 2323; macroscopic.—The rock is pinkish with occasional, fine, black streaks in it, rather fine-grained and fissile, so that it breaks into more or less thin slabs.

Microscopic.—The groundmass consists of cryptocrystalline silica dotted with small, roundish and oval areas filled with small, irregular grains of silica but little larger than those constituting the groundmass. These roundish areas undoubtedly represent tests of Radiolaria, but nothing now remains save the casts.

In another sample tests of Radiolaria belonging to *Stylosphaera, Dictyomitra,* and *Cenosphaera* were identified. The species of the first named could not be identified, but under the second the species *affinis* was distinguished without difficulty;

of the third genus, which is commonest, the species *minuta* and *disseminata* were recognized.

Associated with these red rocks are some green rocks, which a thin section shows to be serpentine; such rocks, it appears, also accompany the cherts of central Borneo.

IGNEOUS ROCKS

As Abella has devoted no little space to the igneous rocks that he found in the cordillera, they will not be discussed at length. Abella's list includes andesite, basalt, diabase, diorite, quartz-diorite, gabbro, picrite, serpentine, tonalite, and trachyte.

Of these the various varieties of andesite constitute the dominant rocks of the cordillera, and similar rocks have been described in Philippine literature. Of the rest attention need be called to only the tonalite and the picrite. I have found these (tonalites) quartz-mica hornblende diorites in various parts of the Philippines, but they are not common. The picrite is a rock rich in olivine, containing also hypersthene and augite. In addition, Abella noted a whitish pulverulent substance in the slide, which he thought might be a decomposition product of nepheline. From Antique Province he cites a basalt that contains leucite and nepheline, a very unusual occurrence in the Philippines.

ECONOMIC DEPOSITS

In the third part of his report Abella discusses the occurrence of various metals and nonmetals. Since Abella's time some prospecting has been done in Antique Province by Americans, with the result that promising deposits of chromic iron and copper have been reported; but nothing of value has been found on the eastern side of the cordillera. The presence of petroleum and coal has also been reported. Specimens of wolframite from Antique Province have been sent to the Bureau of Science by two persons; however, no definite information was given except that they came from near Valderrama. Serpentine containing asbestiform minerals has also been noted in that province.

The presence of petroleum at Janiuay, Iloilo Province, was reported many years ago, but during reconnaissance of the province in 1912 I failed to see any oil. However, at Janiuay I visited a well, 537 meters in depth, which was bored nearly two years earlier by the Bureau of Public Works for artesian water; this was emitting gas and salt water intermittently. The analysis of this gas indicated that it was nothing more than marsh gas.

TABLE 14.—*Record of well 308, Janiuay, Iloilo, Panay.*

Depth.	Drillers' classification.	Remarks.
Meters.		
0– 5	Gravel and clay	
5– 10	Bowlders and clay	
10– 15	Gumbo clay	Gumbo clay is probably a stiff dark-colored clay.
15– 20	Black sticky clay	
20– 35	Joint clay	"Joint clay" is a name applied to the blue clay of the upper clay and shale series in this record.
35– 37	Blue sticky clay	
37– 41	Blue sandy clay and gravel	
41– 43	Clay and gravel	
43– 55	Blue sandy clay and joint clay	Alluvial to 43 meters. Upper clay and shale below 55 meters.
55–124	Joint clay	
124–147	Clay and loose stone	"Loose stone" is probably applied to calcareous concretions which are known to occur in the blue clay.
147–169	Joint clay	
169–175	Joint clay and loose stone	
175–187	Joint clay	
187–199	Volcanic	"Volcanic," possibly a silt which was mistaken for volcanic tuff. The drill penetrated it 12 meters in nine hours.
199–207	Quick clay	
207–247	Joint clay and loose stone	
247–266	Joint clay	
266–273	Joint clay and loose stone	
273–315	Joint clay	
315–320	Joint clay and loose stone	
320–348	Fine sand and gravel	
348–360	Joint clay and loose stone	
360–428	Joint clay	
428–468	Brown sand and clay	
468–490	Joint clay	
490–493	Shale	
493–506	Rock	Rock? Calcareous shale?
506–527	Clay bowlders and quicksand	Clay bowlders?
527–531	Shale mixed with fine black sand	Sand from strata above mixed with shale?
531–537	Sand, gas, and salt water	

LEYTE

There is very little in the writings of the Spanish engineers regarding Leyte that can be drawn upon. D'Almonte, of the old Spanish forest service, made a hachured map of Leyte, a large part of which still serves as our best source of information.

Abella(8) visited the sulphur deposits on Biliran. Jagor in his travels also visited these deposits, and he described them in a monograph published in Madrid in 1885.

About 1909 G. I. Adams(17) made a hasty reconnaissance of the island and published some notes. Adams saw little of the interior of Leyte, still his article is the most nearly complete compilation we have of the geology of the island as a whole. In the chapter on Economic Geology, under the heading of sulphur, I have quoted extensively from Goodman, who visited the sol-fataras at Burauen. In 1915 Pratt(495) made a detailed study of the residual bitumens in the extreme northwest corner of the island near Villaba. I have visited only the locality of residual bitumens near Villaba on the northeast coast and once touched at Tacloban on the east side of the island. A few of the most-pertinent paragraphs from the paper by Adams follow:

* * * The dominant feature of Leyte is the Central Cordillera which runs from Cabalian in a northwesterly direction through the island and is continued in Biliran and Maripipi Islands. In addition may be distinguished the southwestern semi-mountainous district, the northeastern semi-mountainous district and the northeastern plains. There are also some littoral lowlands of small extent which are not shown on the map.

CENTRAL CORDILLERA

This district is for the most part rugged and is dominated by many high peaks. Its lowest portion is to the west of Carigara, where it is also narrowest. This is the most practicable place for a road to cross the district, and a trail now exists which can be developed into a road.

GEOLOGIC HISTORY

Our present knowledge of the geology of Leyte is very incomplete but it points to an interesting history of the island which may be tentatively outlined as follows:

The basal formations do not appear in any area thus far studied unless the dioritic rocks represent the igneous portion of the older formations. Thus far diorites have been found only near Malitbog, and, possibly, as Becker has suggested, they are represented at the gold mines on Panaon Island.

In the northeastern district there is a series of sedimentaries, perhaps older Tertiary, which have been metamorphosed into schists and altered shales by intrusive igneous rocks. Some stream gravels indicate that a similar series of more or less metamorphosed sedimentaries and accompanying intrusives are present in the southwestern district. The erosion of these formations has contributed sediments to the later Tertiary.

The most widely distributed formation is a series which contains besides conspicuous beds of limestone, some shales, sandstones, and conglomerates. It is the predominating formation in the southwestern district and is reported to contain coal near Port Calubian (Eulalia) and petroleum north of Villaba. There is a small area of limestone of this series in the hills at Patyacan point on the east side of the Cordillera in the southeastern part of the island, and it is represented in the northeastern part of the island near the strait of San Juanico, and extensively in southwestern Samar. These sedimentaries are usually considered as later Tertiary. They have

been lifted, faulted, and intruded by igneous rocks which appear to be closely related to the igneous rocks of the Cordillera.

The Central Cordillera of Leyte is a volcanic belt which extends in a direction north 30° west, through the island and continues in Biliran and Maripipi Islands. It contains the extinct volcano Cabalian, the solfataras south of Burauen, Mount Amandiuing, which is probably an extinct volcano, and the solfataras in Biliran Island. The rocks of this district are largely hornblendic andesites.

The northeastern plains, which are largely alluvial, represent the latest extensive formation. In addition there are some marginal littoral deposits formed in part of coralline limestone.

The emergences and submergences of Leyte and the adjacent islands, including especially Samar, form a complicated history. The coal in Leyte (and it may be noted that coal is also reported in western Samar but not yet known to be of economic importance) and the wide distribution of coralline limestone, in what is called the later Tertiary series of sedimentaries, indicates an extensive area of low-lying lands, coral reefs and shallow seas in late Tertiary time. The emergence of this series, which formed the Island of Leyte, seems to have been brought about by the igneous intrusions and volcanic eruptions which took place in the zone of the Cordillera. During the first stages of this process a strait probably extended in what is now the northeastern plains district. By continued elevation and the contribution of sediments from the Cordillera this strait has been transformed into an aggraded alluvial area. The development of the San Juanico Strait apparently occurred later and may be attributed to a submergence along an axis parallel to the Cordillera of Leyte, and perhaps resulting concomitantly with the growth in elevation of the central portions of the Islands of Samar and Leyte.

SUMMARY OF MINERAL RESOURCES

Gold.—The mines in Panaon Island have been abandoned for several years. If the veins permit of favorable mining and a yield of from $6 to $7 per ton can be obtained, as reported by Ashburner, it may be worth while to reopen the mines.

Coal.—The commercial value of the coal near Calubian probably depends more upon the character of the beds and facilities for delivering it at the sea coast, than upon the quality, since most Philippine coals are of about the same grade. Concerning the nature and location of the coal there are at present only hearsay reports.*

Sulphur.—Goodman, from an examination of the surface estimated that there are about 3,000 tons of sulphur in sight at the To-od and Pangujan solfataras south of Burauen [Leyte]. At the mining claim San Antonio on Biliran Island there are 400 tons and at the Santa Rosalia claim the amount is inappreciable. He suggests the deduction of 25 per cent for loss in mining and treating. The cost of transportation from the Burauen deposits he considered prohibitive and the Biliran deposits too small to warrant the cost of installing machinery. However, transportation from Burauen to Tacloban will soon be improved by the completion of a good road, and since the remaining distance is short it may be that the sulphur can be exploited at a profit.

* Elicaño was unable to verify these reports.—W. D. S.

Petroleum.—No wells have been drilled and no study of the geologic structure near the oil showings has been made. There is some talk of prospecting at the showings near Villaba and on Biliran, but at present there is lack of capital for such an enterprise because of the attendant risk.

Stone.—Thus far two quarries have been opened for road material, one just west of Tanauan and the other at Palo. No doubt others will be developed in order to obtain stone of good quality for road building. Up to the present time gravel has been extensively used, but with better equipment crushed stone will be employed for road surfacing and a diligent search will probably reveal that it can be made available at many places.

Clay.—At present, ordinary pottery is manufactured at Tanauan and probably at some other towns which were not visited.

Formerly brick kilns were operated for burning soft brick at Baybay, but after supplying the local demand they were allowed to fall into disuse.

There is some activity (1922) in the vicinity of Villaba. A company is mining and exporting considerable quantities of tuff and limestone impregnated with crude oil for use in road surfacing, and some vigorous prospecting by oil companies has been done. One shallow well was bored a short distance north of Villaba, but work was abandoned before results could be expected.

An interesting memorandum on the physiography of the northwest coast of Leyte, kindly furnished by Dickerson, follows:

Along the trail between Tabango and San Isidro beautiful views of these small bays are had. The massive resistant character of the rocks of the Canguinsa formation forms the picturesque gateways of these bays. Near Arevalo Bay these rocks dip west at an angle of 20°. From the divide ridge between Tabango and Arevalo Bays there appears to be a general even surface which truncates the hills at an elevation of about 500 feet, a possible old marine terrace. This surface was probably developed at or above sea level, as the drainage of the present clearly had an antecedent history, as is evidenced by their courses across the strike of the sandstone of Canguinsa age of Putingbato Ridge and the limestone and shales of Vigo age. Where the rocks traversed by the stream were resistant, the former stream valleys were narrow and the headlands of the bays of the present time were formed in this manner. Such topography and stream development indicate the following history: The first streams developed upon a broad nearly level surface gently sloping to the sea and they cut across the country, then mantled by rocks of probable Pleistocene age. Successive uplifts of Leyte and the vicinity followed. As a result of this movement, the streams were rejuvenated and they proceeded to cut cañons across the hard rock which now became exposed in their courses, and rapidly widened their cañons into valleys in the soft shales of the Vigo group, and later the Visayan Sea invaded the land taking for her own the narrows of the former cañons and portions of the widened valleys within. Recently, the streams with their heavy loads of silt, the reef corals, and the mangroves are aiding the land to recover its own. Such events have resulted

in the production of the surpassing beauty of Arevalo Bay with fine ramparts of white limestone and sandstone guarding its entrance, and surrounding grass-covered hills and green-bordered shore of mangroves.

BILIRAN

Biliran, just off the northeast coast of Leyte, undoubtedly is closely connected with that island geologically. The first and most nearly complete report on Biliran is that made by Abella(8) in 1885, covering the general geology and particularly the sulphur deposits.

I shall simply abstract the essential geologic features indicated in the Spanish report by Abella, as follows:

There is a single cordillera trending northwest and southeast, which reaches a maximum elevation of 1,000 meters. The principal igneous rocks of this region are trachytes; that is, hornblende andesites. Abella mentions no sedimentaries on the island. According to him the island is of volcanic origin, as the solfataras would certainly indicate. In Spanish times the best-known sulphur deposits were those on Biliran, and they were exploited on a comparatively large scale.

On Panaon Island, south of Leyte and virtually a part of that island, some auriferous schists have yielded gold and some prospecting has been done in recent years.

CEBU

Cebu is the long, narrow, mountainous island east of Negros and west of Bohol, in about the center of the Archipelago. Its long axis lies north-northeast and south-southwest with a total length of 216 kilometers; the island is 35 kilometers wide in the widest part, and its maximum elevation is about 1,000 meters. It has the largest population, proportionately, of all the islands of the group, 587,410 in 1918.

A very admirable and fairly complete geologic and physiographic description of Cebu has come from the pen of Abella.(11) As this work is in Spanish, it is not easily available to many geologists; for this reason I may be pardoned for drawing upon it rather freely. As a result of subsequent study, much has been found out that is not in harmony with Abella's early report; but, considering the pioneer nature of his work, this is only to be expected. I have contributed several papers, one on the physiography of the island and one on the Compostela-Danao coal deposits.(561) Dickerson has spent some time on Cebu investigating oil seeps and has given me many reliable suggestions about the geology of the island.

With prophetic insight, the great explorer Miguel Legaspi realized the importance of this island, writing in 1565:

> We are at the gate and in the vicinity of the most fortunate countries of the world, and the most remote; it is three hundred leagues or thereabouts farther than great China, Brunnei, Java, Lauson (Luzon), Samatra, Malaco, Patan, Siam, Lequeios, Japan, and other rich and large provinces.

Legaspi planted the first European colony in the Philippines on the site of the present city of Cebu. This is where Magellan made his first real landing in the Philippines; and just across the straits, on the small island of Mactan, he met his death. This, the first expedition of Europeans, made no permanent settlement on Cebu.

Although Legaspi afterward established another settlement farther north, in Manila, which in the following centuries has outstripped the southern port, Cebu is still the center of trade in the Visayas, and is the distributing point for northern Mindanao as well. One hundred sixty kilometers (over a hundred miles) of standard-gauge railroad, equipped with American rolling stock, have been constructed; there are at least three coal mines, some coking coal, and petroleum deposits (not yet developed); there is a large labor supply, the climate is healthful, and the position of the island is central; a large, modern cement plant has just been constructed at Naga. With these advantages Cebu bids fair to become the chief manufacturing center of the Archipelago.

PHYSIOGRAPHY

In general it may be said that Cebu is largely mountainous (Plate 25), with a very narrow coastal plain fringing the cordillera of igneous rocks, which is partly mantled by sedimentaries and extrusives. The island is predominantly of limestone formation, maturely dissected. There is little or no productive hinterland, and there are practically no navigable streams. The streams are for the most part short and swift.

TABLE 15.—*Physiographic subdivisions of Cebu.*

	Approximate elevation.	
	Meters.	*Feet.*
Central cordillera	850–1,000	2,500–3,000
Uplands	650–850	2,000–2,500
Intermediate uplands	30–650	100–2,000
Coves, a few meters above sea level	30	100
Coastal plains	30	100

The central cordillera.—This comprises all of the most elevated and rugged portion, forming the backbone as it were of the island, where the dominant rocks are igneous or metamorphic. In this portion the streams are in deep V-shaped cañons. The whole country is wild and sparsely settled. The general trend of this cordillera is somewhat east of north. Although in the central part of Cebu it reaches an elevation of 900 meters, it is much reduced in the south and practically disappears in the north.

The uplands.—Between the cordillera and the intermediate uplands lie some plateaulike areas, which Abella called *mesetas* (little table-lands). A fine example of these is the elevated tract between Carcar and Barili. Another lies near the crest of the Cebu-Toledo Road. There is a distinct difference in the character of the drainage on those uplands and in the lower portions of the island, and considerable lack of topographic adjustment between the two is noted in several places. Several examples of hanging valleys are known. The principal formation on these mesetas is limestone. Various explanations have been offered as to their origin; but whether they represent marine plains, base-level remnants, or are due to the limiting growth of elevated coral, as Becker suggested, is still a matter of conjecture.* They are fertile and support many small farmers.

The intermediate uplands.—All the country between the present coastal plains and the upland mesetas is included under this head. These uplands are maturely dissected and are underlain by coal-measure sandstones and shales, and extrusives with much limestone capping.

The coves.—These are the *cuencas* of Abella. They are common in many parts of Cebu. They are roughly circular or oval areas, with floors not much over 30 meters above sea level, and are situated along the various streams. The bottoms of the valleys are usually in shale or marl, the surrounding hilltops are of limestone, and the lower ends of the coves are usually restricted by a harder igneous rock in the form of a dike or laccolith. They originated purely through the differential erosion of hard and soft materials. An especially fine example of these fertile coves is situated just west of Carmen, on the east coast. They make excellent plantation sites.

* Dickerson calls attention to the significant fact that these upland plateaus truncated folded tertiary foundations.

The coastal plains.—The coastal plain of Cebu is long and narrow and is interrupted by swift torrential streams or by low spurs extending from the main mountain mass. These coastal plains, for the most part, are slightly elevated coral platforms with a veneer of alluvial, spread out in broad fans from the mountains behind. They are densely inhabited.

GEOLOGY

The principal formations occurring in Cebu may be represented in the following, somewhat abbreviated tabular statement:

TABLE 16.—*Geologic formations in Cebu.*

Recent.	Alluvial deposits and coral reefs.
Pliocene.	Malumbang: Coral limestone. Marls (Alpaco marls).
Unconformity.	Andesitic flows and agglomerates.
Middle and upper Miocene.	Vigo shales. Lepidocyclina limestone. Batan coal measures.
Pre-Tertiary, probably Mesozoic.	Schists and slatelike rocks Serpentine intrusions.
Pre-Tertiary.	Basal complex, chiefly diorite.

Structure.—That there has been intense dynamism in Cebu is proved by the presence of schists and specular hematites. The age of these schists is clearly pre-Tertiary; in the absence of any conclusive evidence, they may be placed provisionally in the Mesozoic. Their relations to other groups of rocks, like those of the Tertiary, are obscure.

The Tertiary sediments, including the coal beds, are also considerably disturbed, as they are both folded and faulted; but those movements were not so intense. The folding is pronounced nearer the igneous complex, which acts as a sort of abutment, and diminishes toward the coast (fig. 10). Capping the whole mass is a superstructure of Pliocene coral (Plate 25) which was tilted at a lower angle than the older Tertiary sediments below it.

In addition to these foldings and elevations, there has been faulting on a great scale in this island. One of the great fault scarps appears to be immediately behind the city of Cebu, and there is another on the west side of the island (figs. 11 and 12).

Recent elevation, as indicated by terraces on many parts of the coast, is one of the latest episodes in the history of this island.

Becker, in 1901, called attention to the great growth of coral limestone on this island, stating that there was practically no break between the fringing reef along the coast and the coral limestone cap on the crest of the cordillera. There seems to be a continuous mantle of coral over much of the island (except of course for erosion), but there may well be an unconformity between the Pleistocene and the Pliocene reefs.* This I have never noted, for the reason that I was not looking for it, and I am inclined to think that Cebu has been elevated so uniformly that the coral growth has been virtually continuous from the Pliocene to the present.

Petrography.—The lithology of the rocks of Cebu is very much the same as of those of Luzon. The distinguishing feature of the former is the great development of limestone.

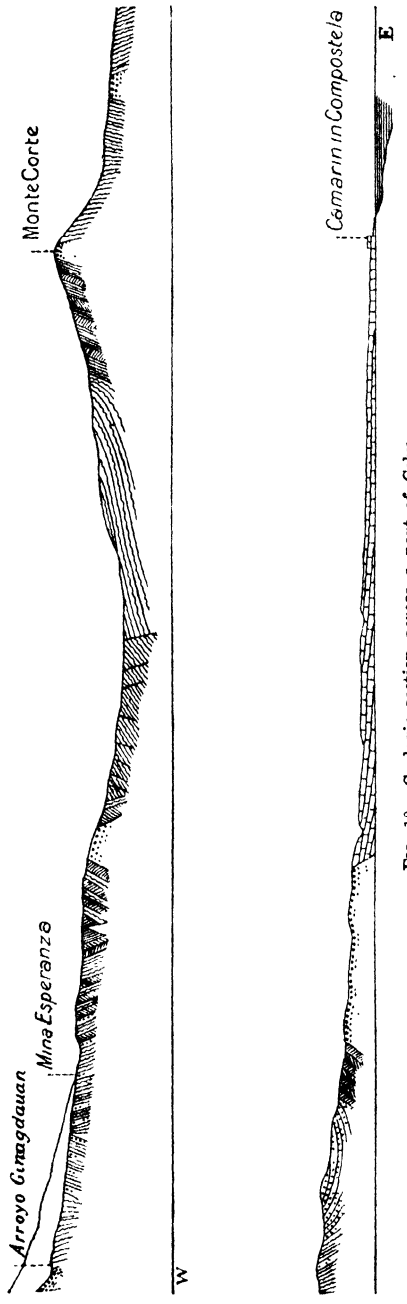


FIG. 10. Geologic section across a part of Cebu.

* Dickerson says that there is very evident unconformity on the road south of Barili, especially in the road cuts there, as well as at a point 2 kilometers north of Boljo-on, on the southeastern coast. In addition, the marine terraces present well-marked physiographic unconformities.

Economic deposits.—Cebu is perhaps provided with more accessible coal fields than any other island of the Archipelago. There are at least four workable seams within 15 kilometers of the coast. The principal fields are Mount Licos, Camansi, Cumajumayan, Uling, and Toledo. There are three producing coal mines of importance and a score of small "gopher" mines. Further particulars are given in the chapter on Economic Geology.

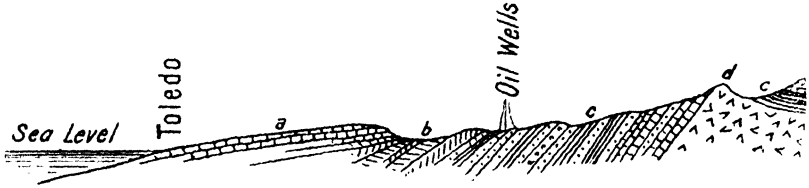


FIG. 11. Geologic section across strike of beds at Toledo, Cebu; partly diagrammatic; *a*, coralline limestone; *b*, tuff and agglomerate; *c*, Miocene shales, sandstones, conglomerates, and limestone; *d*, basal igneous complex.

Petroleum seeps have long been known at Alegria, and near Toledo a well was bored in 1896 to a depth of 400 meters, in which there was a showing of oil, but there has been no production.

Lead deposits at Acsubing, near Compostela, were known and worked to a limited extent in Spanish times.

Some specular hematite has been seen, but no important deposit is known.

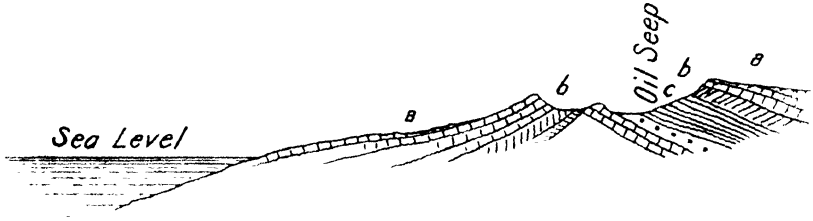


FIG. 12. Geologic section across strike of beds along Malbog Creek, Alegria, Cebu; *a*, coralline limestone; *b*, volcanic tuff; *c*, Miocene shales and sandstones over limestone.

The limestone of Cebu is of value for road metal (the roads of Cebu are among the best in the Philippines), lime making, building stones, etc., and it yields a fairly rich soil on which corn is grown. The chief article of food on this island is corn. To the limestone may be also attributed the generally good health conditions of the island, as there are few undrained areas.

Cebu is an island well favored by nature and ought to play an even greater part than it now does in the history of the Philippines.

BOHOL

Bohol lies east of the southern part of Cebu. There is no reference to Bohol in Becker's monograph and, as far as is known, little in the Spanish literature. I visited the southern part of the island, where much the same formations occur as were found on Cebu. The interior of the island is said to have considerable igneous rock. It is to be presumed, in the absence of more-complete data, that the geology of Bohol will be found to be much like that of Cebu. The most striking feature of Bohol is the remarkable series of "haycock" hills (hundreds of them) in the central part, in the vicinity of Carmen, all alike, having the appearance of a small archipelago of small limestone islands raised some 700 meters. No mines or mineral prospects are known on this island. Guano is now extensively produced from limestone caves.

MASBATE

I have visited Masbate Island many times, to inspect the mining district of Aroroy and examine the coal deposits of Cataingan, and have explored some limestone caves in the interior. No one has done a more comprehensive piece of geologic work in this island than has H. G. Ferguson. His work so thoroughly covered the ground that in the essentials there is to-day no need for correction. In the matter of details and supplementary information, acquired since he did his field work, I may be able to contribute a few interesting items.

The following are excerpts from Ferguson's article:(274)

Bibliography.—It was not until after the rediscovery of gold at Aroroy in 1901 that the island was visited by geologists. However, the earlier writers had noticed the significant form of the island in relation to the principal structural lines of the Philippines. Von Drasche first called attention to this junction of the two principal trends of the Visayan Islands. Koto suggested a similarity to the divergence of the mountain system of the Eastern Alps. Suess noted a possibility of similarity of structure to that of Porto Rico. Becker speaks of two main, curved fissure-systems parallel to the two arms of Masbate.

Mr. A. J. Eveland, at that time geologist in the Mining Bureau, made a short visit to Aroroy in 1904 and noted in his report the topographic youth of the district and the limestone benches on the west side of Port Barrera. Mr. H. D. McCaskey and Mr. H. M. Ickis made a more extended visit in 1906. Mr. McCaskey in his report was the first to call attention to the fact that the great majority of the mineral veins strike in a northwesterly direction, parallel to the principal axis of the island.

The writer published in 1908 a short résumé of the mining conditions and geology of the Aroroy district, and the results of the first season's

field work were made the basis of a more extensive paper on the physiography of western Masbate.

Notes on the mining developments of the year are published in the annual bulletin, the Mineral Resources of the Philippine Islands for 1908. A more detailed statement of the economic geology and mining occurs in the same bulletin for 1909.

THE ISLAND OF MASBATE

Climate.—The rainfall on Masbate is well below the average for the Philippines (2,200 millimeters); observations at Port Palanog (Masbate) for the years 1904, 1905, and 1906 give an average annual rainfall of only 1,446 millimeters. The records show a smaller rainfall at only four out of the sixty-four stations in the Islands. The dry season extends from February to May, inclusive, only 17 per cent of the total precipitation occurring during these four months. Throughout the remainder of the year, the rainfall is distributed fairly evenly.

Population.—The population of the island * * * is small compared with other islands of the Visayan group, and Masbate could easily support a much larger population. The people are for the greater part Visayans, and the language spoken is a dialect of Visayan. There is a scattering of Bicols and Tagalogs, especially along the northern coast. The people are peaceable, hospitable, and friendly, and although of course irresponsible and not very energetic, they make as good workers as are to be found elsewhere in the islands.

Topography.—The Island of Masbate lies almost exactly in the center of the Philippine Archipelago, between latitudes 11° 43′ north and 12° 36′ north, and longitudes 123° 09′ east and 124° 05′ east, and has an area of approximately 4,000 square kilometers. It owes its unique, two-pronged shape to the junction of the two prevailing anticlinical trends of the Visayan Islands and central Luzon. To the inner series, as described by Becker, belongs the western arm of Masbate, which is continued in eastern Panay, Guimaras, and the Cagayanes, and is parallel to the curves formed by Palawan and the Culion group to the west, and the Negros, Zamboanga Peninsula, and Sulu line to the east. The trend of the larger arm of the island is continued through [central] Leyte and eastern Mindanao and is parallel to the outer line formed by Samar and southern Luzon.

Masbate is mountainous and the greater part of the interior is unexplored. A fairly continuous range of hills rises steeply from a narrow plain on the western prong. The maximum elevation of this range is about 600 meters at Mount Gantal. The larger arm of the island is not a continuous range but is broken by two transverse valleys; one between Milagros and Port Palanog, and the other southerly from Uson. Except for these two troughs, the country is extremely rugged and mountainous. The highest mountain in the island, Mount Simbahan, lies 11 kilometers south of the village of Baleno and 18 kilometers southeast of Aroroy, and has an elevation of 660 meters. Two high peaks, Capuluhan and Bagulipat, occur in the mountainous country southeast of the Milagros-Masbate trough. A peculiar feature of the topography of this part of the island is the course of the Malbug River which rises near the northeastern coast and flows southeast parallel to the coast, until near Uson it makes a

sharp turn at right angles to its former direction and flows southwest into the Gulf of Asid. The largest rivers of the island, the Asid and Malbug, drain into the shallow Gulf of Asid. The crests of the mountain ranges lie near the northern shore, there being a considerable stretch of plain and piedmont country on the southwestern side of the main prong of the island. Similarly, the greatest depths near the shore are to be found along the northern and northeastern coast, especially between Naro Bay and Point Bugui, where there is a depth of 911 meters at a point less than 3 kilometers north of Bagubau Point, while off the southern coast shoal water extends for a great distance. * * * The excellent harbors of Port Barrera (Aroroy), Port Palanog (Masbate), Naro Bay (Dimas Alang), and Port Kataingan are situated on the northern and eastern coasts. On the west coast the only harbor is Port Mandaon. The Gulf of Asid, on the south coast, is so shallow that only small boats can call at Milagros.

Geology.—The two cordillera ranges are in part composed of older sediments, largely slates, intruded throughout large areas by diorites and more basic plutonic rocks, and associated with a large amount of later volcanic rocks, of a rather basic type, ranging from rare dacite, through andesite to basalt and leucitite, with accompanying pyroclastics. No fossils are found in the early sediments, but from the great discordance between them and the unmetamorphosed Miocene sediments, I believe that it is not unreasonable to class them provisionally as pre-Tertiary. Scattered outcrops of a dark blue limestone are to be found along the shores of Asid Gulf and inland on the flanks of the mountain range. This occurs as a capping unconformably above the older formations. W. D. Smith has found the characteristic fossil *Lithothamnium ramosissimum* Reuss in thin sections of this rock, and considers the formation to be of Middle Miocene age.

An extensive sedimentary formation of Miocene age, containing coal, occurs between Punta del Este at Port Kataingan and Naro Bay. This series rests upon a base of schistose quartz diorite and is composed of a basal arkose followed by a sedimentary series containing several coal seams which are overlaid by another slightly unconformable sedimentary series. Between Kataingan and Dimas Alang where the writer has had an opportunity to make a reconnaissance of the coal measures, the sedimentary series is found to be bent into a very sharp syncline, the axis of which follows the prevailing northwesterly trend. These sediments in all probability continue northwestward on the unexplored Island of Ticao.

On the northwest corner of Masbate, a similar formation consisting of shales, limestone, and a large development of conglomerate, but so far as now known without coal, extends southwestward from the western part of Port Barrera to Point Mariveles on Nin Bay. There are occasional outliers from these sediments to be found farther inland, but the main boundary shows in a well marked escarpment of limestone and conglomerate. The dip is quite gentle and generally to the northwest, and the submarine contours along the west coast of the island suggest the continuation of the formation for some distance seaward.

Limestones and conglomerates, evidently of quite recent date, occur at several places along the northeast coast, such as Points Vigia (Vihia), Marintok, Bagubau, Kapandan, and Colorada.

Earthquakes.—The Atlas de Filipinas divides the island between "rather frequent" and "rare" earthquake areas, the "rather frequent" zone lying, as would be expected, along the very deep Ticao strait between Masbate and Point Bugui. In a recent catalogue of destructive earthquakes, six earthquakes above VI of the Rossi-Forel scale are stated to have been felt in the years 1869, 1874, 1893, (two) 1897, 1900.

The six major formations that are described by Ferguson as occurring in the Aroroy district, though not widespread in Masbate, may be taken as general for this island. I have rearranged, added to, and correlated these with formations and groups in other islands, as shown in Table 17.

TABLE 17.—*Correlation of the Aroroy geologic formations.*

Coral reefs, river deposits, etc.	Pleistocene and Recent.
Port Barrera formation.	Malumbang Pliocene.
Panique formation; volcanic flows, agglomerates, and tuffs.	Unconformity.
Mountain Maid formation; foraminiferal.	Upper Miocene.
Cataingan formation; coal measures.	Batan and Vigo (?), middle Miocene.
Lanang formation; conglomerate-sandstone.	Lower Miocene (?).
Aroroy quartz-diorite.	Intrusive into the Kaal "slates."
Kaal formation; argillites.	Mesozoic (?).

The most interesting of these is the Kaal formation which is fully discussed in the chapter on Stratigraphy and Correlation. Ferguson sums up the geologic events in Masbate in these words:

Summary of geologic history.—The Kaal formation, the oldest known in the district, is entirely of sedimentary origin and must have been derived from an earlier land mass of which no trace exists in the district. At some later time the intrusion of a large amount of quartz diorite took place, only a small portion of which is exposed in the area covered by the map. Following this, the land was exposed to long-continued erosion which laid bare the mass of the quartz diorite intrusion. The uplift, which bowed up the southeasterly anticline which to-day forms the backbone of the island of Masbate probably came in late Eocene times. A period of vulcanism accompanied this uplift, during which the dike flows and pyroclastic rocks which constitute the Panique series were formed. The principal period of vein formation followed close upon this. The universal northwesterly trend of the veins is evidence that the fissuring was resultant upon the continued bending up of the anticline. Even later than this period of vein formation, igneous action again took place, as is shown in the dike on the Gold Bug claim. The leucite tephrite is in all probability of the same late date. A little later, or perhaps contemporaneous with the intrusion of these dikes, there was faulting in an east and west direction in the region of the present Guinobatan River. Mineralizing solutions filled these fissures giving the minor series of east and west

veins which cut the older and more important series. Probably somewhat earlier than this time the submergence took place which resulted in the deposition of the Mountain Maid limestone, since on its northern border it seems to be cut off by an easterly vein. However, this isolated occurrence of limestone must remain a puzzle for the present.

After the period of vein formation, submergence and the laying down of the marine sediments occurred; these sediments are now found in their early form in the extreme southern part of the area and in a later phase on the opposite shores of Port Barrera. After the sedimentation had gone on long enough to build up a very considerable mass of conglomerate, sandstone, and shale, a further change of level took place, resulting in an unconformity which is marked by the conglomerate found above the shale. The pebbles of vein quartz and andesite composing this conglomerate show that the Panique formation and the veins were then exposed to erosion and enable us to date the period of vein formation with moderate certainty as between late Eocene and early Miocene. Submergence again continued, giving the series of limestone terraces that form such a prominent feature of the topography between Point Colorada and Point Bugui. It is to be inferred from the courses of the present streams that the Aroroy district itself was at one time, at least in great part, covered by sediments. None of the principal streams shows adjustment to the present topography, and all may properly be classed as superimposed. After the period of sedimentation, the land surface was elevated to a point probably some sixty meters above its present level, and remained at this elevation long enough for a deep valley to be eroded out of the soft shales. Recent depression has converted this valley into the present Port Barrera. Still more recent elevation, but only to the extent of some five or six meters, is shown in the raised coral reefs found on the northern shore of Point Colorada and on the coast east of Buyuan Bay.

ECONOMIC MINERALS

Gold is the principal economic mineral of Masbate, and practically all of it comes from the Aroroy district in the northern part, where it is found in quartz in the Miocene andesite. An account of operations in that district is given in the chapter on Economic Geology.

Masbate has deposits of native copper, which are found at Milagros disseminated in andesite.

Lead ore also is found at Milagros, where prospecting is being carried on by Mr. Paul Schwab. Manganese ore, in the form of pyrolusite lenses in the Kaal formation, occurs on Guinobatan River.

At Cataingan some coal deposits have been prospected, but there has been no production.

BATWAAN CAVES

Masbate has, besides the largest gold production of the islands of the Archipelago, the further distinction of having some of the most interesting caves, with prehistoric remains, yet found

in the Philippines. In a limestone outlier (Plate 26) of Malumbang (Pliocene) resembling a citadel, in the center of a great flat-bottomed valley near the center of the island, are several caves which, in company with Mr. Paul Schwab, I explored in the fall of 1920. In these caves were found prehistoric skeletons, flat-headed skulls, stone implements, kitchen middens, and ancient burial paraphernalia. From a study of these remains it seems that more than one stage of culture is represented, and I am inclined to place some of these remains in the Neolithic. Some certainly antedate the Spanish period.

The stone implements are the most interesting, since this is the first authentic find of such in the Islands; that is, with any data which might throw light on them. Two or three other specimens of stone implements have been found, but with scarcely any information as to locality, position, etc.(599)

ROMBLON, TABLAS, AND SIBUYAN

Some marble is quarried on Romblon.

Judging from the appearance of the shore formations and the topography (the island is flat-topped, whence its name), Tablas is largely limestone. The island is comparatively low and appears to have suffered marine planation. No mineral deposits are reported.

Sibuyan is so markedly different from Tablas that it demands a note, even though little is known of its geology. Sibuyan is very high, having one peak, Mount Sibuyan, 2,052 meters, which is undoubtedly an old volcanic stock rising sheer on one side (the west) from the sea. This side of the island is so precipitous as to suggest the existence of a fault of great magnitude.

There are numerous other small islands in this portion of the Archipelago which it would undoubtedly be profitable to study, but unfortunately we have no reliable first-hand data concerning them.

MINDANAO

The great southern island Mindanao extends from 6° 30′ to nearly 10° north latitude and from 122° to 126° 30′ east longitude, a region of comparatively lofty mountains, beautiful lakes, primeval forests, and long and deep rivers. The island is roughly shaped like a cooking pot, with Zamboanga Peninsula as the handle. At various times this has been a not inappropriate description of the island, as something was usually boiling in those parts. The coast line of Mindanao is very much

indented, and as a result there are some remarkably fine bays and harbors.

For many years we were indebted to d'Almonte,* the intrepid and industrious topographer of the Spanish Inspección de Montes, for the best maps of Mindanao; but since his time much work has been done by United States Army topographers, the Philippine Constabulary, and various other organizations. The latest and most accurate map, of the interior at least, is that of the Constabulary. Of the maps of the coasts, however, those of the United States Coast and Geodetic Survey are by far the best.

The interior of this great island is sparsely inhabited by degenerate Moros and wild pagan hill peoples. The settlements are all on the coast and can be counted upon the fingers of one hand. Recent colonization undertakings in Cotabato Valley are very successful, and in time thrifty Filipino settlers will be more numerous.

The absence of typhoons, the fairly even distribution of rain throughout the year, the equable temperature, the great number of waterfalls and long, navigable rivers, the large areas of unoccupied fertile land, the fine forests, the rich volcanic and alluvial soils, and the large coal and iron deposits are features that help to make Mindanao the most desirable island of the Philippine group.

The outstanding features of the island are the long, narrow, mountainous peninsula Zamboanga; the great, north-flowing Agusan River; Cotabato River and the great, fertile plain bordering it; the high-level lake Lanao; the line of dormant and extinct craters in the Buldun Range; Mount Apo, the crowning peak in the Matutum Range and the highest point in the Philippines; and the Bukidnon Plateau.

PLAINS AND RIVERS

Mindanao has not a great proportion of coastal plain. The time that has elapsed since the last important diastrophic movements has not been sufficient to cause the formation of large plains, and mountains everywhere border the sea. The only coastal plain of considerable importance is that of Zamboanga; it is confined to the lower end of the peninsula of the same name and, roughly, is 12 by 35 kilometers in extent. It has a foundation of coral reef with a veneer of piedmont deposits. One

* Atlas de Filipinas, Manila (1899).

small stream, the Tumaga, straggles across it to the sea. The plain is very fertile and is the home of a large and mixed population of Moros, Filipinos, Chinese, Americans, and a few Europeans. The city of Zamboanga, because of the fertility of the surrounding plain and its exceptional situation, occupying a "gate" position with respect to southern Mindanao and Celebes, has risen to first rank among the settlements of the south. However, the lack of navigable water in Tumaga River will hinder the development of Zamboanga. Furthermore, the interior is exceedingly rugged and incapable of supporting other than restless hill tribes or mining camps.

The only comparatively large plains in Mindanao border Cotabato and Agusan Rivers, which are, approximately, 400 and 300 kilometers in length. The width of these valleys varies from only a few kilometers to 50 or 60. The material constituting these river plains is for the most part fine alluvium derived from many classes of rocks passed over by the rivers en route. It is, of course, excellent soil.

COTABATO PLAIN

Beginning at the lower end of Cotabato River, there is a true delta formation, the river making its way across this through several channels (two of them much larger than the others), and debouching in four different places. The two main branches are the Cotabato (north) and the Tamontaca (south). Between these a network of estuaries affords easy communication by boat between the many settlements on the plain. The true delta extends inland to the junction of the two main branches at Tumbau. The valley above this, for 30 kilometers or so, is not so wide, because the low Silik Hills come down fairly close to the river on the north side; the river then makes almost a right-angled bend to the north. Southeast of this point there is a wide, low tract, 50 or 60 kilometers across, containing two bodies of water, marked on the map as Lakes Liguasan and Buluan. These are little more than swamps, their size varying with the rainfall. This great tract is gradually draining, possibly due to slow rising of the land. The evidences of recent and considerable elevation in Mindanao are abundant. The swamp area might be artificially drained should this island ever become extensively colonized.

From this point to the northward the valley plain continues with varying width. Some low hills appear to the northeast at the junction of the Kabakan and the Cotabato. This point,

which is about 160 kilometers from the mouth of the river, is the farthest reached by me in traveling up the main valley. From this point I turned east, following up Kabakan River. Ickis, who made a trip from Cagayan, Misamis, to Sevilla on the headwaters of the Pulangi, reported extensive open country on both sides of the river in that vicinity.

North of Fort Pikit and east and west of Malitabug River are some fairly high elevations, with rolling grassland or terraces near the river. East of the Malitabug lies Mount Kitubud, the principal topographic feature in that vicinity. This is a limestone eminence with a steep western escarpment. The Malitabug flows in a beautiful limestone gorge along the western base of this mountain.

West of the Malitabug, about 15 kilometers away and roughly parallel to it, is the Babuy Range, of andesites and basalts. This is about 1,000 meters in elevation and defines the western limit of the Malitabug watershed. The rocks underlying the country between these two elevated tracts are Tertiary sandstones and shales which yield the characteristic rolling hill and swale topography of that region.

In the vicinity of Fort Pikit are several low hills of about 50 meters elevation (on one of which the fort is located) which are made up of elevated coral reefs of Pleistocene age, giving evidence that this central basin of Mindanao was an arm of the sea in the Pleistocene.

It seems reasonably certain that the region south of Cotabato River was once separated from the northern part by this same arm of the sea, which also extended from Cotabato to Sarangani Bay. The existence of raised coral reefs south of the river points to the correctness of this supposition with a fair degree of conclusiveness. The stretch of country east of Lake Liguasan is underlain by loose sandstone which probably is not very old. The rocks of the Matutum Range, a much interrupted line of volcanic stocks, are andesites which have poured over the country in rather recent times.

The largest settlements of Maguindanao Moros are to be found at the lower end of the Cotabato River plain. Cotabato, a town of about 1,000 civilized inhabitants, is situated about 10 kilometers, by river, from the mouth. Cotabato has in some respects a more favorable geographic situation than either Zamboanga or Davao. Any town situated at the mouth of a navigable river draining an interior like that of central Mindanao possesses great advantages over those not so situated; therefore,

now that Mindanao has been opened to colonizers, Cotabato should become the metropolis. Cotabato has one serious disadvantage in the shallow bar at the river mouth.

Cotabato River * has its source in the mountains east of Cagayan, Misamis, and flows almost due south to the southern boundary of Bukidnon Subprovince, swings west to the town of Sevilla, then east again in a wide curve, and then southwest; a few kilometers north of Lake Liguasan it turns at right angles and flows in a course a few degrees north of east into Illana Bay. It is quite probable that the former mouth was very close to Lake Liguasan or even at Sarangani Bay. A damming of the lower course by a lava flow from some vent in the Matutum Range might explain its present swing at right angles and its consequent longer journey to the sea, or irregularities of coral growth and accumulation of flood débris when the lower Cotabato Valley was an estuary might explain the river's present course. Meanders are common in this river, and there is one point near Tumbao where, by utilizing a small canal 50 or 75 meters in length, over half an hour of travel can be saved. The banks show no rock exposures; nothing but mud could be seen as far as I followed it. The fall is only about 1 in 5,000, as the 30-meter contour crosses the river at 10 or 12 kilometers above the confluence of the Kabakan and the Pulangi, or about 160 kilometers from the sea.

It is difficult to navigate any but light, flat-bottomed craft above the Kabakan. A flat-bottomed, stern-wheeled steamship drawing not over 60 centimeters should be able to ascend 80 kilometers above this point, and might reach Sevilla, were it not for Murphy's Rapids, which Captain Murphy describes as occurring in the vicinity of Alanan River. I suspect that an outcrop of some hard, igneous dike occurs here. Unfortunately, the Army topographers collected no geologic specimens in the course of their work in this part of Cotabato Valley; perhaps with good reason, for all through Mindanao traveling and packing are extremely difficult. The United States Army engineers have made an excellent topographic map of a large part of Mindanao River and the region it drains, particularly that to the north. The topography by Captain Murphy and his associates in this region shows that the old maps were very broadly generalized, to say the least, and in many instances totally wrong. The regular, linear arrangement of north and

* Sometimes termed the Pulangi and the Rio Grande de Mindanao.

south tributaries as shown on the Spanish maps or the later American editions, while substantially correct, was greatly exaggerated.

Terraces along this river are well shown, following the south fork below Tamontaca and on the north branch back of Ungup, and again near the confluence of the Libugan and the Rio Grande. Between the town of Cotabato and old Fort Tamontaca there is an extensive, raised, flat-topped platform which rises like an island in the delta. This was examined and found to be a raised coral reef 5 to 10 meters above the level of the river.

The Cotabato River overflows its banks periodically and thus irrigates and enriches an already marvelously fertile soil. Rice is the chief crop produced, but the methods of agriculture are primitive, except in the new agricultural colony tracts.

AGUSAN VALLEY

Goodman(299) has described this great intermontane area. However, he does not give definite figures as to its width. It is wide in places, as is attested by the fact that the distant mountain peaks could be seen with difficulty. This broad valley must be approximately 300 kilometers long. It is inhabited by Christian Visayans, Manobos, Mandayas, Mangguañgans, and Bukidnons, the first named having immigrated there. Mr. G. B. Moody, a geologist in private employ, has kindly furnished a few notes on this region as follows:

The most striking feature of the topography of Agusan Valley is the great flat "sink" bounded roughly by the barrios of Martires, Novele, Bunawan, Veruela, and Gracia. This area, comprising about three hundred square miles, is a vast network of canals connecting lakes and marshes and traversable only in barotos. There are said to be a few isolated fragments of dry land within this marsh area during the so-called "dry" season of Agusan.

The valley is about 20 miles wide in this region. South of Veruela and Bunawan the valley floor becomes elevated and the Agusan River is separated at the 8th parallel from its chief tributary, the Simulao River, by about ten miles of low hills. The east side of Agusan Valley rises abruptly to form the Surigao Mountains, while the west side climbs somewhat more gradually into the rugged mountains separating Agusan Province from Bukidnon Province. The narrowest portion of Agusan Valley is in the neighborhood of San Mateo where steep hills crowd into the valley from both sides. From San Mateo to Butuan the valley widens again and at Butuan is about twelve miles wide, this most northerly part of the valley being, in reality, a part of the coastal plain.

The topography of Agusan Province has unquestionably been largely affected by faulting. Adjustment is still continuing along the fault zones, according to seismological reports.

The lakes mentioned by Moody are supposed to have originated in a local subsidence at the time of the earthquake of 1892, which was very much like that causing the formation of Reelfoot Lake in western Tennessee in the United States. The description given by an American civil engineer, formerly supervisor of Surigao Province, confirms this view. He said that many trees of a kind not usually growing in water could be seen submerged so that only the top branches were visible. This is not at all unreasonable, in view of the fact that the valley of the Agusan is a focus of great seismic activity.*

There is little transportation over this plain. The river and its tributaries still constitute practically the only means of transportation for hemp and rice, the chief agricultural products of this fertile valley.

SMALL RIVERS

Besides the two main rivers of central and eastern Mindanao, there are several shorter, unnavigable ones in various parts of the island. The following will be considered: The Sahug-Tagum system, the Agus, the Mataling, the Cagayan, the Iponan, and the Tumaga. Others, which are much longer than the last mentioned, but as yet of little commercial importance, are omitted.

The Sahug-Tagum system, which consists principally of the Tagum and its main tributary, the Sahug, has its source on the southern slopes of Mount Kuanabayan. This is the route Ickis and Goodman took in the early part of 1908 to pass from Davao Gulf to the upper waters of the Agusan. A much shorter way, and one more frequently traveled, is by way of the Hijo to Compostela. Practically the only published data regarding Tagum River are taken from Goodman's narrative. He describes it as a tortuous stream, about 90 meters wide at its mouth, but only about 30 at the confluence of the Sahug and the Tagum; at this point its banks are 5 meters above the water level and the formation is a brown and blue clay overlying sandstone, probably Vigo (Miocene). At Matinlud the river shoaled so much that a loaded banca could not be floated. The country it traverses is all heavily wooded and occupied by Mandayas. Dr. J. Montano, a French traveler, also made this trip, but he gives very meager notes on the physiography of the region. A

* Goodman thought that abnormally high water was sufficient to account for these lakes. It is quite probable that in 1902, when the civil engineer visited them, there was a flood.

map is given in his book(447) showing a long ridge at right angles to the Apo Range and curving to the northwest. Goodman also mentions this ridge. Montano gives some geologic notes, to which reference will be made in the next section of this chapter. He published a sketch map which is taken probably entire from d'Almonte.

Agus River, but 32 kilometers in length, drains Lake Lanao, which is 671 meters above sea level. It has an average fall of 20 meters per kilometer, which however is not uniform, for at Maria Cristina Falls there is a sheer drop of 58 meters. The river is very narrow and swift and flows over a basalt formation throughout its length. Army engineers have ascertained the depth and width at Momungan to be 26.5 and 15.5 meters, respectively. The flow of water, measured by Mr. Bradshaw of the Bureau of Public Works, at Pantar Bridge, amounted to 9 second-meters, giving approximately 40,000 electric horsepower.

The Mataling is another short river with a considerable fall. It rises in the ridge south of Lake Lanao, and flows southwest into Illana Bay. It likewise flows over a basalt formation, and at Mataling Falls drops over a hard layer of this rock into a pool 16 meters below. From here on the rock is much softer, and the river a kilometer or two beyond flows through a low plain of loose, bluish black, volcanic ash. The Mataling is very narrow, 10 meters on an average, and very swift. Its source in part is undoubtedly Lake Lanao, although no connection is apparent on the surface; it also receives the run-off from Danao Lake, a small body of water near the southwest corner of Lake Lanao.

Several very important rivers in the northern part of Mindanao rise in the mountainous interior of Bukidnon Subprovince and flow north through Misamis Province into Makahalar Bay. The most important of these are the Iponan, the Cagayan, and the Tagoloan. For many decades, perhaps for centuries, they have been favorite localities for gold panning. Ickis traversed and mapped one of them, the Tagoloan, throughout its whole length. This river shows some interesting features. It rises near Tibua Mountain and is separated by a very narrow strip of moderately elevated country from the headquarters of the Pulangi, flows northwest in a valley with long, gentle slopes up to Mount Katunlud on the west but with very rugged hills on the east. In the upper part of its course its tributaries join it, making an acute angle upstream in the normal way,

but below the confluence of Manguina and Tagoloan Rivers the latter enters a narrow gorge with only one side stream coming in from the west in a distance of 19 kilometers, but with twenty-four entering, approximately at right angles, from the east (fig. 13). This remarkable drainage arrangement must be due to faulting and jointing. There undoubtedly was a local uplift east and west across the courses of these rivers after they had become well established. The country south of their headwaters becomes more open and flat.

Tumaga River is very small and scarcely navigable for more than 1 to 1.5 kilometers from its mouth. It is mentioned here because of its importance to Zamboanga as a source of potable water. It is not much over 30 kilometers in length and very narrow and shallow. It rises on the slopes of Mount Panubigan, flows about due south over schists and along their strike until it issues from the Zamboanga gorge onto the plain, where after a short distance it turns shortly to the east. Just what has so sharply deflected this stream is not apparent unless, perchance, during a freshet it deposited on the plain near Zamboanga a great load of detritus which afterward turned its course to the east. A slight warping of the coastal plain would also account for this eccentricity.

THE INTERMEDIATE UPLANDS

Under this heading is comprised all the territory lying between the plains and the cordilleras. With the exception of the Diuata Range in eastern Mindanao there is no marked cordillera on the island. The Matutum Range east of Agusan River, the Kulingtang and Buldung Mountains south and east of Lake Lanao, and the range of low mountains in the Zamboanga Peninsula are not of sufficient height and continuity to warrant placing them exactly in that category.

By far the largest portion of the area of Mindanao, then, should be considered as simply upland country. The central plain of Mindanao is fairly low. The principal upland areas therefore are the peninsular part south of Lakes Liguasan and Buluan, known in part locally as the Tiruray table-land; the Lake Lanao upland; practically all of Zamboanga Peninsula; the Davao upland, the tract in which rise Sahug, Sabul, and Agusan Rivers; and the Bukidnon Plateau.

THE TIRURAY TABLE-LAND

The Tiruray table-land is practically unexplored. I have been on the edge of it near the Tamontaca and have sketched

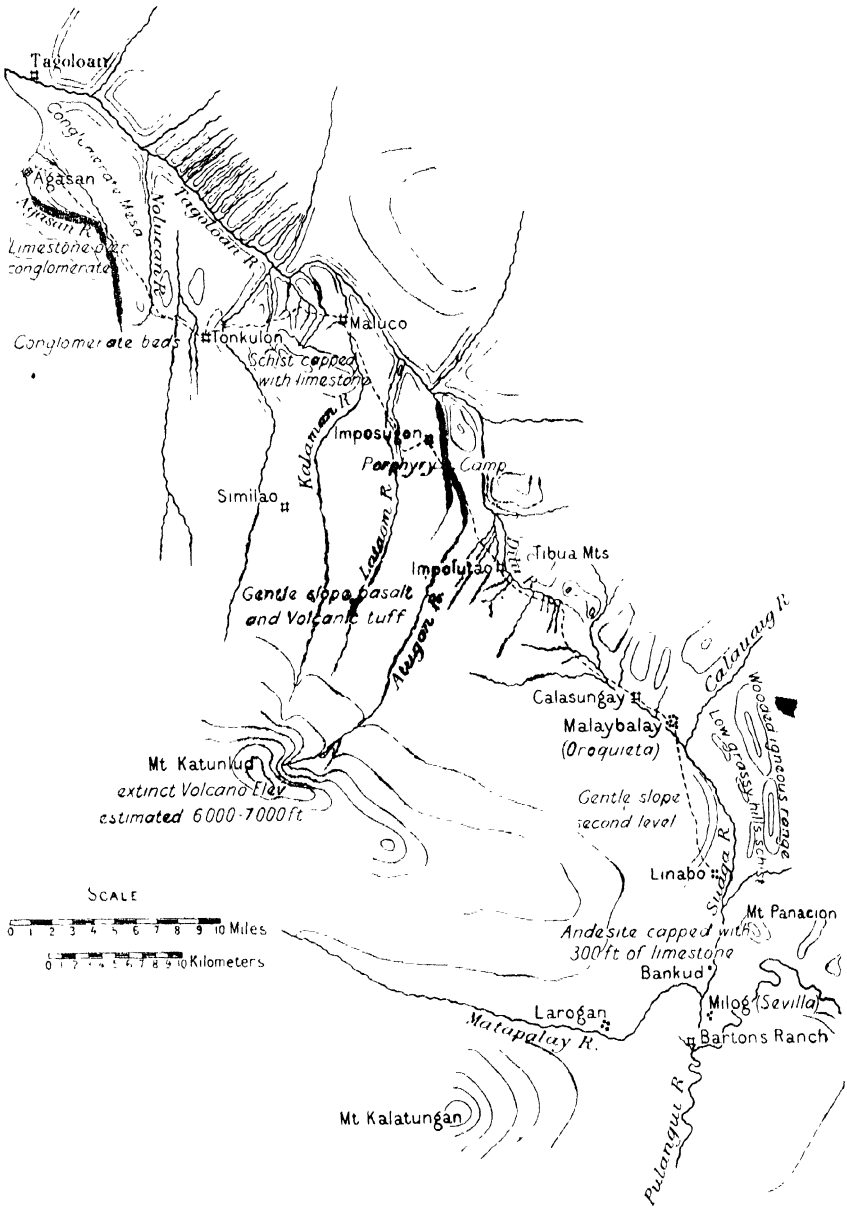


FIG. 13. Drainage system of Cagayan de Misamis River, Mindanao. Topography along Tagoloan River, by H. M. Ickis.

the southern skyline. Several prominent points, Mounts Blik, Itim-Itim, and others, rise above the general level; their elevation is between 350 and 450 meters. Although this portion of Mindanao has some resemblance to a table-land, the surface of the country is in reality uneven and whatever approximation to uniformity of skyline exists in parts of it is apparently fortuitous. Of course there is the possibility that peneplanation may have occurred. However, there are not enough data to permit of any definite statements being made on this point. The people inhabiting this territory are Tirurays, a degenerate band of Moros, Manobos, and Tagabilis, largely pagans.

THE LAKE LANAO UPLAND

This tract, bounded on the north by Iligan, on the south by Illana, on the west by Panguil Bay, and on the east by the Kulingtang Range, is one of the most interesting in the Philippines. The average elevation is about 600 meters. Lake Lanao is 686 meters above the sea, but some of the country to the west is lower, while certain of the most prominent points, such as Mount Gurayu, are over 1,220 meters in height. The surrounding country is for the most part treeless, and is covered with a rich, red soil. Cogon grass is the chief vegetation. Physiographically, the Lanao upland is striking. It bears a very suggestive likeness to the elevated prairies of the middle west of the United States. A profile from Camp Overton to the lake and south to Malabang is shown in fig. 14. One very interesting feature of the topography is the Keithley escarpment, a bold ridge with an abrupt northern face and a long, gentle slope southward to the lake. It is the belief of many people who have seen this country that Lake Lanao occupies a crater. The topography of the country in general, and particularly that of this escarpment, does not lend much encouragement to this supposition. There is good reason for the opinion that it is simply a basin between two well-defined mountain ranges, that has been dammed by lava flows and an unusual accumulation of wash from the hills.

To the southwest of the lake the land, which is sparsely inhabited, falls away in long, grassy slopes toward Malabang on the coast. On the east side there is a rather large tract of perfectly level, somewhat swampy land, with a fairly bold, heavily wooded range behind it. A large population of Moros is found on this side of the lake; they are known as the Lanao, or Lake, Moros.

The Lake Lanao region and the uplands of Bukidnon are the

most favorable in all Mindanao for white settlements, since they are high and cool, and possess wonderfully rich soil, particularly adapted to coffee growing and cattle raising.

ZAMBOANGA PENINSULA

The Zamboanga Peninsula owes its origin to a sharp upward flexing of sedimentaries, which are overlain by a veneer of volcanic material. It is, strictly, a cordillera, but of only moderate elevation. It is practically all upland country, but well dissected. The chief characteristics of this region can be enumerated as follows: It is long and narrow; it has a moderate elevation; it has a great number of indentations in the coast line; it has a small development of coastal plain; it is topographically in early maturity, with occasional, longitudinal streams and a great number of short, swift, consequent streams at right angles to the main trend of the peninsula; and there are superimposed high points, rising above the general uplands, such as Mounts Panubigan, Dapiok, and Malindang, which are mostly old volcanic stocks.

The region is inhabited almost exclusively by Subanuns, a primitive non-Christian hill people who have evidently fallen back before the Moros.

THE DAVAO UPLAND

This upland area is not very large. It comprises the country between Apo Range and Agusan River. Its most prominent feature is a fairly well-defined ridge which trends east and west and northeast. Its highest two points are Mounts Panombayan and Kuanabayan. Very little is known about this country. The only scien-

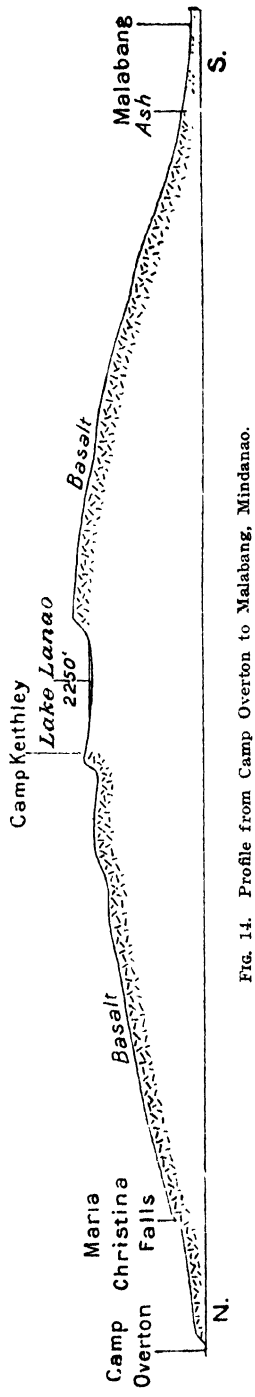


FIG. 14. Profile from Camp Overton to Malabang, Mindanao.

tific observers * who have traveled through it are Montano, who paid more attention to ethnology than to geology, and Ickis and Goodman. Montano's geological observations relate only to the character of the rocks, and hence should properly be considered later.

BUKIDNON PLATEAU

From Goodman's description it is evident that the country is rather rough and heavily timbered, with occasional clearings in which the long-haired Mandayas live. There is, however, a fairly low pass, not over 400 meters in elevation, across this divide.

The following notes have been kindly furnished me by Dr. Albert W. C. T. Herre, chief of the division of fisheries of the Bureau of Science, who recently visited Bukidnon:

From Cagayan de Misamis one travels eastward along the bay shore in a coconut grove for about half or three quarters of an hour by automobile. Turning abruptly southward, a steep ascent brings one out on the plateau at an elevation of about 600 meters (2,000 feet). Here we find a gently rolling grassland plateau which comprises the greater part of Bukidnon. To the left or east lies the great gorge of Tagoloan River, which with its bare mesas, sharply outlined crags, and precipitous rock wall resembles those seen in many parts of the western United States.

Mount Kaluntanglad, a rock mass more than 2,400 meters (8,000 feet) in height, occupies the center of and dominates the Bukidnon Plateau. From it spring all the streams that flow northward into Macajalar Bay, as well as those that flow eastward and southward across the plateau. To the east, separated by hills and mountains, lies the Pulangi which starts far to the north almost bisecting the island, while beyond it is the vast range of lofty forested mountains forming the western boundary of Agusan Valley.

The drainage systems of Bukidnon are very complicated, and from suitable vantage points in central Bukidnon one may distinguish the overlapping entanglements of river basins as they flow in opposite directions in the same general region.

None of the published maps is at all accurate. The best one is a blue print of the province, and it is inaccurate for southern Bukidnon. I have seen none in which the streams are shown correctly.

Passing Dikum, Dilirig, Tangkulan, and Maluko, the country is much the same, rolling grassland with deep cañons here and there, their banks often of vertical sandstone † walls for great heights. Beyond Dilirig a great hill lies to the right or west, terminating southward in a vast vertical

* This does not take into consideration geologists for private corporations who usually do not publish the results of their work.

† It is probable that this is not sandstone but tuff or tuffaceous sandstone. According to G. B. Moody, who has been through that country lately, this plateau is a lava plateau; he saw no sandstone in that particular section.—W. D. S.

cliff resembling white (limestone?) battlements, visible for many miles. The road gradually ascends to Delauangan, the highest point of the road, and then descends a few hundred feet to Malaybalay, which I was told was about 1,000 meters (3,000 feet) altitude. Sawaga River has here cut through sandstone beds of considerable thickness, but there is more or less igneous rock (lava) evident throughout.

Along the channels of the larger streams there is more or less forest, and even the small ones have tree ferns, bamboo, and various woody plants and trees scattered along their banks, but on the whole there is no forest visible except along the large rivers and on the higher mountains. The forested area cannot extend, owing to the custom of burning off great areas of grassland every year. As a matter of fact the forested area is being reduced in extent through the combined influences of lumbering, fires, and clearing for agriculture.

The soil is in general thin and in many places more or less covered with lava fragments or volcanic ejecta. It is characteristically red or reddish, though farther south along river bottoms it is black and of very great fertility. The climate is relatively cool, resembling that of parts of southern California near the coast, and at night one needs substantial covering. Rains are very frequent, almost daily for most of the year, though usually light. In the high mountains heavy rains and thunder storms are practically of daily occurrence. Permanent streams are therefore numerous.

A few miles north of Malaybalay the road reaches its greatest elevation, and about fifteen miles south of Malaybalay the plateau begins to descend and gradually merges into the lowlands of the Cotabato. Near the pass where one leaves the grasslands to reach the forests southward are volcanic peaks, including one small cone of beautiful symmetry. To the westward is Mount Kalatungan, very much smaller and lower than Kaluntanglad, but still a very important feature. A trail leads off westward between these two mountains, a branch going southwest to some remote settlements in the forests, another continuing northwest to the plains around the headwaters of the Cagayan and back to Tangkulan or westward by untraveled ways to Lanao.

All Bukidnon except the southern forests is wonderfully well adapted to cattle raising, possessing climate, grass range, and water. Pineapples thrive, as do coffee and citrus fruits. Wheat, corn, and rice cannot be raised because of locusts, so that the food crops are sweet potatoes (camotes) and cassava (camoteng cahoy). Southern Bukidnon is admirably suited to coconuts and abaca, but these are prohibitive because of transportation difficulties.

From Malaybalay one can travel three days horseback to Lepanto on the Pulangi, where boats may be obtained for Kabaka, and the Cotabato. The Pulangi is a large river far up in Bukidnon, and its tributary, the Sawaga, is navigable at Mailag, but two or three large falls below make the Pulangi impossible to navigate until Lepanto is reached.

THE CORDILLERA

As has been said, the only considerable cordillera is that east of Agusan River trending with and extending the entire length of the coast. The higest (?) peak is Mount Hilonghilong, 1,837

meters elevation. Very little accurate information about this region is at hand. Ickis crossed it from Talacogon to Lianga, but his untimely death prevented his making a report on what he had seen. There are two other prominent trails across this cordillera, one from Compostela on the upper waters of the Agusan to Cateel, the second the route taken by Goodman from San Juan to Mati. This region is inhabited largely by Mandayas.

Exceedingly rugged topography would be expected in this region, because it is on the edge of the great continental horst. It is one of the most humid districts of the entire Archipelago. The rainfall at Caraga on the eastern side of the cordillera from September, 1902, to August, 1903, was 3,165 millimeters. This was exceeded in only three other places in the Philippines; namely, at Borongan, east coast of Samar, and Masinloc, west coast of Luzon, and at Baguio.

From the fragmentary notes we have on this portion of the country I infer that the rocks of this cordillera are much the same as those in the cordillera of Luzon.

LAKES

There are at least twelve lakes known in Mindanao. In order of size they are: Lanao, Liguasan, Buluan, Linao, Mainit, Kadagan, Malanao, Leonard Wood, Balut, Dapao, Butig, and Munay.

Lake Lanao has already been referred to under another head. Lakes Liguasan and Buluan are simply the remnants of a greater body of water which formerly occupied all the central low country. Lieutenant Van Horn, United States Army, made an exploring trip in 1902 from Cotabato across the Tiruray tableland to Makar and back by way of the valley between Mounts Malitabu and Matutum. He was of the opinion that the Rio Grande once flowed through Lakes Liguasan and Buluan along the depression now followed by the trail through Talik and Tambatu. This is very probably true. These lakes are very shallow, being little more than swamps. Lieutenant Van Horn in his manuscript report to the Adjutant-General says:

> Our route was through Buluan River connecting the two lakes. The entrance to the river from Lake Buluan was not more than a meter wide on account of being choked by floating islands of grass, but it widened to about 40 meters for about 5 kilometers. It was hard to distinguish the river from the numerous esteros. After 7 kilometers we came to some solid ground on the left bank where there was a *tiangi*, or market. After this we could see no solid ground on either bank until I reached the Rio Grande. Buluan River is very swift, so swift in the channel we came down that vintas must go up by another route. In one place we passed

over a small fall about three-quarters of a meter in height, the turn at the bottom being very sharp and we going so fast that our vinta was forced through the high grass on the bank about 9 meters. Entered Lake Liguasan about 1 p. m. The lake was very much the same as the surrounding country, a few patches of open water, large floating islands, and the rest covered with lily pads and water cabbages. A small channel was made by boats cutting their way through. The character of the lake changes with every wind.

These lakes are very probably residuals of a greater body of water in this region.

Lakes Linao and Kadagan, already referred to, are not much more than marshy areas where Agusan River has spread over a large tract of low ground including several small lakes, of which Lake Linao is the largest. These bodies of water are very shallow in places; in others trees are partly submerged. They are navigable for bancas (dugouts), and in one place a channel navigable for light-draught (1 meter) launches has been located, beginning near Bunawan and ending in the main river.

Lake Mainit is a smaller lake, more pear-shaped than it appears on the older maps, about 9.5 kilometers in diameter, situated near the northern point of Surigao Peninsula. Its name, meaning hot, its shape, and the more or less high land around it point to the possibility of its being a caldera, or it may have been caused by peripheral faulting, as in the case of Lake Taal, on Luzon Island.

Montano,(447) in 1881, wrote as follows concerning Lake Mainit:

> The large lake af Mainit, situated at the center of the peninsula, at an altitude of 40 meters, seems to be the crater of an ancient volcano; it is circular, very deep, and its banks are very steep; it is surrounded by high mountains, where hot springs abound.

He calls attention in another paragraph to some limestone caves on the east side of the lake, which Goodman also saw.

Besides the moderately large lakes already discussed, there are several smaller ones, like Malanao and Balut near Cotabato; these are little more than ponds in the chance depressions in the topography. The same is true of Butig Lake near the southeast corner of Lanao.

Lakes Munay, Dapao, and Nonungan are due to depressions in the basalt flow which covers most of that region.

Information concerning Lake Leonard Wood is confined to a brief mention in a report to the Adjutant-General, United States Army, by Capt. C. C. Smith, Fourteenth Cavalry, concerning an expedition made in June, 1904, from Misamis to Dumanquilis

Bay. This lake has an altitude of 889 meters, is shaped like a figure 8, and, roughly, is 8 kilometers long by 3 kilometers wide. It is not shown on many maps of Mindanao.

VOLCANOES

There are no active volcanoes in Mindanao. Mount Apo has some vents on the eastern slope which emit steam and sulphurous fumes, but the mountain is in no sense active. Bulut and Camiguin, both of which are near Mindanao, have active volcanoes. Volcanism, which is now merely an incident in the life of the island, was at one time the dominant feature. The period of volcanic activity was probably the Pleistocene, when Mindanao was taking on its final shape; then Mounts Matutum and Apo near Davao Gulf, Buldung * Mountains south of Lake Lanao, Mount Malindang west of Panguil Bay, and the mountains near Lake Mainit were, in all probability, belching forth lava and ashes. Now they are all quiet; if not extinct, at least they are dormant.

We find that the volcanic centers in Mindanao, which seem scattered indiscriminately over the country, in reality lie along certain definite lines which intersect and form a triangle. These trend north 6° west, north 68° east, and north 53° west. Catarman, the active volcano on Camiguin Island, is located at the northern end along the first line, and Mount Apo at the southern. Mounts Panubigan, Tres Reyes, Sugar-loaf, Malindang, and Camiguin are situated on the second line with Lake Mainit (Caldera) and its hot springs almost on it. The third line runs through the Lanao cluster of old cones and southeast to Mount Apo. Mount Apo and the Kulingtang cones preserve much of their former shape; the others are much more worn and dissected by erosion, so that they are now little more than volcanic stocks. Mount Malindang is a very imposing pile of andesite and basalt, rising to the commanding elevation of 2,800 meters from the shores of Iligan Bay. It was ascended in 1906 by the late Lieut.-Col. E. A. Mearns, United States Army, and his party.

THE KULINGTANG-BULDUNG RANGE

As the traveler rides toward the south down the long grassy slope from Camp Vicars on the edge of Lake Lanao, he has before him a magnificent panorama of this long range with its numerous burnt-out craters, arranged in steplike fashion, due to different elevations, like so many blown-out blast furnaces.

* Mount Ragang in this range was reported to be active in 1915.

THE APO VOLCANIC CLUSTER

Mount Apo is the highest peak in a volcanic cluster on the west side of Davao Gulf. This volcano is described in the chapter on Volcanology.

I have no first-hand information concerning Catarman, the only active volcano (except Ragang) which might be considered as belonging to Mindanao, it being on the little island of Camiguin off the Misamis coast. An extensive account of this volcano and the eruption of 1871 has been written by Saderra Masó,(429) which is quoted in the chapter on Volcanology.

CORAL REEFS

Coral reefs are perhaps the most conspicuous of the shore features that vitally affect the life and customs of the inhabitants of the island. They are found in scattered patches all around the island. The growth is not great on exposed coasts like the stormy eastern one; but in sheltered bays, like Dumanquilis, it is exceedingly difficult to navigate because of the reefs. The prominent part that reefs have played in the formation of Mindanao can readily be realized when the raised reefs in many inland parts, particularly in the valley of the Rio Grande, are seen.

TERRACES

One of the most striking of all physiographic phenomena, the significance of which is not always appreciated, is the terracing along the seashore and on the sides of the valleys.

The terraces of Cotabato Valley have already been mentioned. These are in part marine wave-cut, in part river terraces, and partly due to the elevation of reefs. In the upper valley of the Malitabug, about 60 kilometers north of its junction with the Rio Grande, there are some fine terraces of flood-plain origin. There are three very distinct ones and two less marked, making five in all. The best farming and grazing land in this central region is on these terraces. Such terraces, of course, are indices of the recent uplift in central Mindanao and are to be correlated with the marine terraces on the coasts. However, the most striking terraces are those along the present seashore. Exceptional examples are to be seen, as at Point Blanca, on the northwest coast of Mindanao, where there is a raised delta of an old river. It is sliced off at the sea margin so that the structure is clearly revealed. In this soft material exists a sea cliff of from 6 to 9 meters elevation (estimated from the boat). Formerly, the lower end of this delta was at the level

of the sea. The structure, as now apparent, is that of a typical delta with the cross-bedding found in such formations. Another striking example is that in Macajalar Bay. Here the terracing is very pronounced.

The meaning of these terraces, raised deltas, and beaches is that Mindanao, in some quarters at least, has risen. The amount of elevation is as great as 500 to 600 meters; it varies from only a few meters to the maximum in different parts of the island.

The latest and most extensive geologic exploration made in this island is that by Mr. Graham B. Moody. As a result of his work he concludes that in Pleistocene times there were five islands where now there is the one large island. He asserts that formerly (in the Pleistocene and early Pliocene probably) there was an island where Zamboanga Peninsula now is; a long narrow island east of Agusan Valley; another, to the south of Cotabato River; a fourth, near Lake Lanao; and a fifth, between Bukidnon and Agusan Valley. I saw enough of this island during my reconnaissance to confirm the probable correctness of Mr. Moody's conclusions. In fact, a depression of the island of not over 30 meters would cause a flooding of the entire Cotabato and Agusan Valleys and give an irregularly shaped island having the general pattern of the "drowned" island Celebes.

This closes the discussion of the main physiographic features on Mindanao. Until recently geologists could not work in this region without a military escort; and travel, owing to the absence of roads and settlements, has been and still is difficult; hence the paucity of detailed information. This is one of the newest (in many parts at least) and most-interesting portions of the Philippine Archipelago.

Though our knowledge of the island is far from complete, and systematic physiographic studies have not been made, it seems clear that the physiographic history of Mindanao is in some respects very different from that of Luzon, certainly of northern Luzon. There appears to be no old-age plateau like that of Baguio. The Lanao and Bukidnon Plateaus have had a different origin from that one. Again, there is nothing in Luzon comparable to Cotabato Valley and its raised Pleistocene reefs in the interior of the island. A third marked difference is in the apparent restricted distribution of the older massive crystalline rocks, which throws light upon the physiography, and points to the fact that for the most part the island is young.

The great extent of comparatively recent volcanic extrusives and the considerable development of raised Pleistocene reefs gives one the impression that the dominant processes in Mindanao have been aggradational rather than degradational.

GENERAL AND ECONOMIC GEOLOGY OF THE DISTRICTS OF MINDANAO

In the preceding section of this chapter the physiography of Mindanao is discussed by units; that is, lakes, plains, etc. The geology by districts (which more or less closely conform to the political divisions) follows, and in each case the various physiographic features are briefly reviewed.

Geologically, Mindanao is to be considered a part of the great chain of outliers of the ancient Australasian continental platform, as it is situated at the very edge of that horst;* the formations which appear at the surface to-day would normally of course be the youngest. The principal tectonic lines run generally north and south, but they are more or less arcuate, thus conforming approximately to the southern Asiatic coast line. The deepest known part of the Pacific lies directly off the east coast of this island;† hence, Mindanao marks the eastern edge of the great continental block.

On a hydrographic map of the Philippines (Plate 37), the former and presumably rather recent connection between Mindanao and Sulu and Borneo is readily seen. In all probability there was a former connection with Celebes by way of Sarangani and Karkaralong Islands.

Some interesting facts in the distribution of animals and plants can be explained by these former land bridges, but these will not be discussed here except to state that in the Philippine flora and fauna there are two sharply defined elements; one, the Australian and Moluccan, which must have come in by way of the Mindanao-Celebes bridge, and the other, the Indo-Malayan, which was introduced by two routes; namely, the Borneo-Palawan bridge and via Borneo-Sulu-Mindanao (Zamboanga Peninsula).

So far as is now known, there are no rocks in Mindanao and Sulu which can with certainty be said to be older than the

* Formerly, I referred to this as the edge of the continental shelf. It may be the ancient shelf, but it is not the present shelf. Between the Philippines and China there is a considerable deep which points to a separation of the Philippines and Asia longer than that between Formosa and Asia.

† Ann. d. Hydrog. u. mar. Met. (1906) 556.

Tertiary, though there are slates and schists which may presumably be Mesozoic. This territory apparently has emerged from the sea so recently that the streams have not been able to cut through the overlying formations to the older ones below except in a few places, and but little excavation and boring has been done. Mindanao differs in this respect but slightly from the rest of the Archipelago.

As it is almost impossible anywhere to see other than very limited geologic sections, much must be left to conjecture in regard to the succession of formations in Mindanao. Still less can be observed in Jolo, where practically everything is blanketed by recent volcanics. However, by piecing the isolated facts together we arrive at the provisional scheme shown in Table 18.

TABLE 18.—*Provisional stratigraphic scheme.*

Recent:
- Coral reefs.
- Piedmont deposits.
- River alluvium (Cotabato plain).
- Andesitic and basaltic ejecta.

Unconformity.

Pleistocene:
- Pikit raised coral reefs.
- Volcanics.
- Banisilan (embayed deposits) sandstones and shales.
- Malitabug terraces.

Unconformity.

Pliocene (Malumbang):
- Coral limestones and marls.
- Volcanics.

Marked unconformity.

Andesitic and basaltic flows and agglomerate.

Miocene (Vigo and Batan series):
- Lepidocycline limestone, sandstones, shales, coal and oil, sills and intrusions of andesite and basalt.
- Some sandstones and shales apparently of this period on Zamboanga Peninsula are schistose.

Pre-Tertiary:
- "Old slates."
- Some schists.
- Plutonics.

ZAMBOANGA DISTRICT

Geography.—In Zamboanga district will be included Basilan and Zamboanga Peninsula to a line extending from Sindangan Bay south to Sibuguey Bay. This territory is characterized by its rugged topography, indented coast line, lack of consider-

able coastal plain, numerous reefs, short, shallow, and swift rivers, heavy forests, and few important settlements.

The only large settlement is Zamboanga, situated at the edge of the broad plain at the southern extremity of the peninsula. As has already been said, Zamboanga is a "gate city," its importance being due to its location at the intersection of several trade routes. It owes very little to the country immediately back of it. The importance of this will be seen on a comparison between it and such localities as Cotabato and Butuan. Zamboanga does not even lie near a river.

The greater part of the coastal plains of Zamboanga and Basilan is largely inhabited by Moros, a constantly shifting population, living most of the time in boats and coming ashore only to trade. Of late years many Visayan immigrants have settled in and around Zamboanga. The rugged interior of Basilan is peopled by Yakans, who are called "Hill Moros," and the Zamboanga Peninsula by Subanuns. The Subanuns are a very primitive people who have retreated before the advance of the Moros and now live in a nomadic state, constantly changing their abode from one clearing to another.

The Zamboanga plain is well adapted to coconut growing, as it has a more or less sandy soil and is exposed to the sea. The hill country of the peninsula has little cultivated land; camotes are practically the only crop raised. The hot and moist valleys between the ridges are excellent locations for abacá growing.

Stratigraphy.—As elsewhere in the Philippines, good geologic sections are difficult to find in Zamboanga Peninsula. However, some satisfactory exposures of limited extent can be seen in the gorge of Tumaga River and at several points along this stream to the north. By piecing together the information gathered from scattered outcrops, the stratigraphic succession can be approximated. The basal rock, as in the northern islands, is probably a diorite, although I have seen this only in pebbles in the streams. Presumably above this diorite lies a basal conglomerate. The next formation in the peninsula proper is a schist, which may simply be metamorphosed sandstones and shales. This schist, dipping about 45° east, is found best exposed in the beds of the streams that run along the long axis of the peninsula. It is completely buried in other localities by later volcanic flows and alluvium, but can be well seen for about 24 kilometers along the bed of Tumaga River. It is a grayish to green rock, with a considerable development of chlorite along

the planes of schistosity, and is characterized by numerous small stringers of auriferous quartz. In thin section it is seen to consist of long, frayed-out, green hornblendes and chlorite with granular quartz and feldspar, with the quartz dominant, these two minerals lying between the fragments of hornblende. The schistosity is strongly marked in the microscopic slide. The large amount of quartz seems to confirm the supposition that it is a metamorphosed sandstone. Other samples show and abundance of chlorite and some small sections of apatite. I found an outcrop of fossiliferous shale near the gorge of Tumaga River, the relation of which to the schist I was unable to determine. However, I believe it must be much younger. This shale is identical with that overlying the coal seams in Cebu, and contains the well-known fossil *Vicarya callosa* Jenkins, which occurs just above the coal in the Visayas and in Luzon.

Next above the schist comes andesite, which is the dominant rock in Zamboanga Peninsula. A large amount probably was derived from an old vent now represented by Mount Panubigan, a peak of some 1,220 meters elevation, about 80 kilometers north of Zamboanga. This andesite so completely covers the underlying rocks that the occurrence of schists and other formations in Zamboanga Peninsula was not noted by earlier geologists.

While traversing a small stream east of San Ramon farm on the west coast of the peninsula, I found pieces of schist included in the andesite, which demonstrated that the latter was of later origin than the former and while in a molten state had caught up loose fragments of the underlying formation and subsequently had cooled around them. Von Richthofen mentions the finding of nummulitic limestone in a piece of float near Zamboanga. I also found pieces of this float; but, while I could see no *Nummulites*, I discovered fragments of *Lepidocyclina* in it. I found none of this limestone in place. However, in the central and higher part of the range there may be remnants of this formation.

It will be recalled that von Richthofen found so-called *Nummulites* in the Binangonan limestone near Manila, in Luzon. It is clear that the Zamboanga limestone and the limestone of Binangonan Peninsula are equivalent, and they are Miocene and not Eocene. As a result of the considerable exploration work carried on by the National Coal Company in Sibuguey Peninsula we fortunately are in possession of much valuable geologic data. Dalburg, who was consulting geologist for that company

for a time and who was formerly coal engineer in the Bureau of Science, describes the local topography and geology as follows: *

Topography.—Sibuguey Peninsula is formed by a comparatively narrow ridge that starts with the Kaladis Mountains to the south and terminates in the Tres Reyes Mountains.

The principal drainage systems are Sibuguey River on the west and Malongon and Dumaguet Rivers on the east.

The elevation of the Kaladis Mountains is about 600 meters and Tres Reyes about 400 meters. Between these two mountain ranges the ridge reaches an elevation of 190 meters.

The Lapirian Range is the most rugged part in the west central area. From the Malangas side the general rise of the country is gradual and in part is over an alluvial plain. On Sibuguey River the slopes are very steep over short distances and erosion has been very extensive and deep.

The southern part of the peninsula is somewhat broad, and the coast is marked by deep indentations. The peninsula terminates in Olutanga Island, which is comparatively low in relief.

Geology.—General statement. Sibuguey Peninsula is made up mostly of igneous rocks, with sedimentary rocks exposed at several places but not of great extent.

The sedimentary series is principally thin-bedded shales and sandstones with some thin limestone beds. The coal beds occur in this series and are of Tertiary age and belong to the Miocene period. The measured sections show a thickness of over 300 meters, and the base of the sandstone series is not exposed. The strata have been forced into folds along lines northeast and southwest. The folding has resulted in a principal syncline that starts from Tantanang Bay toward Gotas and no doubt extends northward along Sibuguey River.

The western side of the peninsula is a monocline, and the presence of the syncline is only noted by the fact that the strata at Gotas and Butong dip toward each other. Butong lies on a small anticline. Along the general monocline there are minor folds and faults that have caused some cross folding and reverse dips.

The erosion has been extensive and in some cases at Lumbog and Lalat the seams, in isolated patches, lie exposed on the surface and conform to the topography of the country. First the upper part of the measures have been worn away and practically leave the seam lying on top of the hill or along the slope of the stream bed.

Covering the coal measures in the Butong River district is a basalt flow that is a much later age and rests unconformably upon them.

Stratigraphy.—Recent or alluvial. Along the coast and indentations of the large bays is an alluvial with bowlders from the basalt flow and follows along the several rivers toward the foothills.

Tertiary rocks.—The deposits in which the coal was originally formed are a part of a series of sedimentary strata laid down when this part of Mindanao was largely submerged. The shales and sandstones form the lowest rocks that are exposed, resting on a greenstone that may be only a metamorphic stage of the lowest sandstone. The lower sandstone is

* Manuscript report.

medium grained and full of concretions. Above this sandstone come the coal measures proper.

The coal measures consist of shales and sandstone, with some thin-bedded limestone. At least eight beds of coal are recognized.

Late igneous rock.—On top of the coal measures is a porous basalt flow the relative thickness of which has not been determined. One section shows it to be over 100 meters thick. A geologic section in the cut above No. 14 Mine Gotas, is as follows:

	Thickness, meters.
Soil	4
Red-brown shale	2
Soft coal	0.40
Red and black shale	7
Gray shale	0.45
Soft black shale	0.50
Gray shale	0.30
Coal	0.25
Gray shale	1.80
Coal	0.20
Shoddy	0.15
Coal	0.10
Shoddy	0.10
Coal	0.05
Gray shale	0.10
Carbonaceous shale	0.25
Gray shale	1.00
Hard gray shale, calcareous	0.70
Banded shale	2.50
Coal	0.04
Banded shale	2.76
Carbonaceous shale	0.08
Coal	0.20
Shale	0.08
Coal	0.20
Shale or bone	0.02
Coal	0.35
Shale	0.04
Coal	0.35
Shoddy	0.25
Gray soft shale	0.03
Shoddy	0.30

Structure.—The main structure of the peninsula is a monocline that has a trend northeast and southwest. There is evidence of a syncline between Gotas and Butong, as the dips are toward each other. There are local minor folds that cause small anticlines, faults, and rolls that have disturbed the beds. The fold at Gotas is a plunging anticline with the nose dipping northeast. In several places the beds have been so displaced as to make them vertical. The Butong shaft is also on a small anticline of very flat dips.

Classification of igneous rocks.—The basaltic lava between Butong and Gotas appears to be the remnant of a surface flow that covered a considerable area. This lava is considerably younger than the coal measures and has protected them from erosion. The coal measures dip toward this mantle of basalt which shows a synclinal trough, unless there has been faulting previous to the laying down of the basalt rock.

From Payao to Balian and an area in the vicinity of the Lapirian Mountains is mostly covered by an igneous rock. This rock is similar to the basalt flow between Butong and Gotas and is classed as an andesite. This classification is based simply on lithologic appearances. Under the hand lens the rock is coarse-grained and seems to contain less olivine.

The igneous rock which occurs as a flow and is exposed in various places from Malangas to Butong and Gotas is a porous basalt. Lath-shaped crystals of plagioclase feldspar is the most abundant constituent. Some olivine and augite grains are noted in the groundmass. There is some brown basaltic glass and the rock is iron-stained with particles of magnetite. Calcite has filtered into the formation from an extraneous source and deposited in some of the cavities. Due to weathering and erosion great bowlders of this rock are found on the slopes and in the stream lines, generally columnar in shape.

In the stream lines north and east of Butong are great igneous bowlders, which have never been found in place. These bowlders belong to a massive igneous formation. The rock is light green and seems to be about half orthoclase and plagioclase feldspar. There are some hornblendes, quartz, magnetite, and epidote in the groundmass. This rock has been classed as a monzonite; it no doubt comes from some of the mountain ranges north of Tres Reyes.

Laterite.—A large part of Basilan, as well as many portions of Mindanao and Sulu, is covered with a heavy red soil. This material seems to be, in spots, more in the nature of an iron formation than a soil. In some places it is hard and carries a considerable percentage of iron; in others, it is simply a highly ferruginous clay. Laterite appears to be the best name for this deposit, as it seems to correspond in many ways to a similar formation or formations so named in India. It is characteristic of the Tropics where weathering extends to a considerable depth and where the surface rocks are rich in iron minerals, as is the case over a large part of western Mindanao and the Sulu Archipelago. The origin of laterite has been much discussed, and hundreds of pages have been written defending first one theory and then another. The Philippine formation that I call laterite seems, in general, to be a product purely of weathering. There is a similar and more-important deposit in Surigao.

Soil.—The soils of Basilan are excellently adapted to the growing of rubber and abacá.

My observations on Basilan were limited to the northern part, in the vicinity of the town of Isabela. Wherever I went and as far as I could see from the boat, I found the island largely covered by a mantle of andesite and basalt. It is a densely wooded region with numerous volcanic cones and gentle slopes. The soil is heavy and red. A typical specimen of basalt, exceedingly fine-grained, was taken from the hill just back of Mr. Musser's plantation. The chief minerals are plagioclase (labradorite and anorthite), augite, olivine, and magnetite; in addition, innumerable minute grains of highly refracting substances occur which might easily be confused with zoisite, vesuvianite, or corundum. They are almost colorless, have a bluish, sometimes greenish cast, a high index of refraction, low double refraction, and no pleochroism. They correspond to the substance noted by Buching in the basalts from Breitfierst. The texture of this basalt is pronouncedly ophitic. Another rock obtained from Basilan, which is in the old collection of the Spanish mining bureau, is a gabbro. This consists of a perfect network of rods or lath-shaped plagioclase (oligoclase) with more or less granular pyroxenes (diopside or diallage) in the interstices of or partially intergrown with the feldspars. There is also some magnetite. The granular appearance of the pyroxenes is due to the basal cleavage. An analysis of Basilan gabbro is given in Table 6, in the chapter on Petrography.

MALINDANG DISTRICT

There is little definite information regarding the Malindang district. Maj. Edgar A. Mearns, United States Army, ascended Mount Malindang in 1906, but has left practically no record of the geology encountered. An exploring expedition from Misamis to Dumanquilis Bay was undertaken in 1904 by a detachment of Troop G, 14th Cavalry, under Capt. C. C. Smith. A route map was made and the report submitted to the Adjutant-General of the Philippines; however, this gives no geologic information. The chief value of the map to those outside of the Army is the fairly accurate location and sketch of Lake Leonard Wood near the rancheria of Payan.

In December, 1907, I visited the town of Misamis, on the west coast of Pangil Bay, and in company with Lieutenant Lattamore, Philippine Constabulary, went to several points around Pangil Bay. I found everywhere a rich, red soil (splendid agricultural country) very much like that of the Hawaiian Islands; the rocks, wherever exposed, were basaltic or andesitic. Mount Malindang

is evidently an old volcanic stock and shows signs of extensive erosion; it has probably not been in eruption since the Pleistocene. There are several other old stocks in this district. A fine strip of coastal plain extends north from Misamis through Jimenez, or Oroquieta, to Langaran. This coastal plain varies from 1 to 12 kilometers in width and is very fertile agricultural land.

The country is very rugged west of Malindang; there are several prominent peaks, of which Mount Dapiok and Sugar Loaf are the most conspicuous. The north coast in the vicinity of Dapitan is of the same character and gives every evidence of recent elevation. I did not land at Dapitan, but went close enough to the shore to be able to make out limestone cliffs with the glass. No deposits of economic importance are known in the district. There should be an abundance of coal and limestone which might be developed. It is fairly safe to predict that gold also will be found in many of the streams. The hill country of this district is inhabited by Subanuns; the coast towns are peopled largely with Visayans from Cebu and Negros and with Chinese.

LANAO DISTRICT

The Lanao district has already been referred to in speaking of the upland of Mindanao. It is the upland territory bounded on the west by a line from Pangil to Illana Bay, on the north by Iligan Bay, on the south by Illana Bay, and on the east by the Kalintang Range and the hills of the western part of Bukidnon. The country rises gradually from Pangil Bay to the irregular group of mountains west of Lake Lanao. The lake itself is 670.5 meters above sea level. East of the lake there is a range varying from 760 to nearly 2,400 meters in height. The country north and south drops off gradually from the lake to the sea.

Geology.—I crossed this region from east to west and north to south and found very few outcrops other than basalt. That this basalt is a blanket overlying sedimentaries is proved by the finding of sandstone on the east side of Lake Lanao; at Parang sedimentaries can be studied emerging at the edge of the basalt. Before discussing this basalt, it is better to consider the region beginning at Camp Overton. The military road starts there and immediately climbs in a zigzag up the steep escarpment which faces the bay. For the first hundred meters or more, it cuts through raised coral reefs (which constitute a series of terraces) and rubble limestone up to about 30 meters

elevation; then it passes out of the limestone, and from that point to Lake Lanao is entirely in basalt. I made no detailed study of the corals in these exposures, but they appear to be identical in species (certainly in genera) with those living in the sea immediately below. These Pleistocene raised reefs and marine terraces are undoubtedly to be correlated with those in the interior of Cotabato.

At Maria Cristina Falls the Agus drops 58.3 meters over a cliff of basalt to the gorge below. The principal part of the formation is a hard, olivine basalt, with a tendency to columnar jointing. In the vesicular spaces there are white to greenish yellow minerals (usually one of the zeolites) with radial structure; some rays are over a centimeter in length. Calcite also is found in some of the specimens.

About halfway down the side of the gorge the formation changes rather sharply to an agglomerate in which are numerous bowlders. The lower part of the formation is very porous, and water issues in little streams from many points in the side of the cliff.

Under the microscope the rock is seen to consist of the following principal minerals: Labradorite feldspar, rhombic pyroxene, olivine, and magnetite. Some of the plagioclases are more than 5 millimeters in length. The pyroxenes are almost as large. The groundmass consists of an ophitic mat of well-defined, lath-shaped plagioclases, among which are scattered roundish grains of pyroxene, olivine, and magnetite. The rock at Mataling Falls south of Lake Lanao is of very much the same character.

The traveler, after leaving Mataling Falls, very soon passes into an extensive deposit of bluish gray volcanic ash. This continues to Malabang on the coast.

I have already stated that I found one outcrop of sandstone near Malaig River, which drains Lake Budig and flows into Lake Lanao. This sandstone was much weathered and closely resembled that overlying the coal in Cebu. It is not at all improbable that drilling at this point would reveal the coal measures below the level of the lake.

During a trip, in 1908, from Iligan into the hills southeast for a distance of about 15 kilometers, I found andesite agglomerate, and in the beds of the streams picked up many pebbles of schist which must have been brought from the hills on the boundary line between Lanao and Bukidnon. About 2 kilometers from Iligan I saw a little residual limestone, from which I procured the fossil *Turbo borneensis* Bttg.

Putting all of these facts together, it appears that the stratigraphy of Lanao is much the same as that of the Zamboanga district. At the base there is diorite, as evidenced by the diorite pebbles in Iligan River; above this, sericite and chlorite schist; then, sandstone, and probably the whole coal measure series, which may prove to be contemporaneous with some of the schists; above these the basalt; and, finally, piedmont deposits around the border of Lake Lanao and those along the lower reaches of the river.

Economic deposits.—This country was for a long time in a disturbed political condition, so that very little prospecting has been done. While at Marahui on the north coast of Lake Lanao, I heard reports of the existence of copper in Taraca River. Ickis and I visited the Taraca River country in 1908 and panned in the lower reaches of the stream without success, finding neither gold nor copper. The turbulent state of the Moros prevented following this stream much farther than the limits of the jurisdiction of the datu with whom we stayed; to one who knows anything of this district, it will be clear why we did not go very far.

Soil.—As the underlying rock is largely basalt, the soil is naturally rich in iron. It is heavy and red when exposed. There is scarcely any timber left in this upland country, save in the ranges to the east and south of the lake. It would seem that this ought to make an excellent cattle country. It is also especially adapted to coffee growing.

COTABATO DISTRICT

The Cotabato district lies between Lanao and the Tiruray table-land. It received its name from the town of Cotabato, which is situated near the mouth of the Rio Grande. Physiographically, it is largely made up of bottom lands along the Rio Grande. A portion of this bottom land is under water, a large area being covered by Lakes Liguasan and Buluan. The moderately elevated hill country begins on the slopes of Kalintang Range and extends south to the river. The course of the Rio Grande is described in another chapter.

One of the scenic features of this central part of Mindanao, and one of the most picturesque and unique in the Philippines, is the gorge and the natural bridge of the Malitabug, a tributary of the Rio Grande and a wild torrential stream. On the west side of Mount Kitubud there is a great fault scarp of nearly 300 meters, at the base of which flows the Malitabug. For some distance between Banisilan and Bao this river flows

through a limestone gorge, which the old Government trail follows some 100 meters above the water. At one place the gorge narrows and the trail passes over a limestone arch, which forms a natural bridge. This trail was built in order to obviate the necessity of fording the Malitabug which, for about six months of the year, is impassable.

Mount Kitubud (Plate 17, fig. 2), a peak of about 800 meters elevation and, presumably, a fault-block mountain, is the dominant feature in the landscape.

North of the Rio Grande the country is rugged, with numerous mountains like the Babuy Range, consisting of intrusive and extrusive andesite and basalt with folded and faulted Tertiary sedimentaries in the foothills. South of this river the country is almost perfectly flat as far as the Tiruray upland, and underlain by alluvium.

The stratigraphic sequence as tentatively worked out by me as a result of my recent reconnaissance in that region is shown in Table 19.

TABLE 19.—*Provisional stratigraphy of the Pidatan oil field, Cotabato Province, Mindanao.*

Period.	Formation.	Lithology.	Estimated thickness.	Remarks.
			Meters.	
Recent	Malitabug	River terrace deposits.	75	Five terraces.
Pleistocene	Pikut	Raised reefs	50	Species of modern reef corals.
Lower Pleistocene or upper Pliocene.	Banisilan	Coarse sandstone and shales.	200+	Marine and estuarine deposits; also abundant shells; contain fragments of cogon leaves and stems of reeds.
Unconformity				
Pliocene	Malumbang	Upper coral limestone. Marl Sandstone	300+	Fossil corals, very similar to those above mentioned. Contains numerous casts of pelecypods. Contains isolated fragments of reef corals.
Unconformity				
	Babuy	Andesitic agglomerate and intrusives.	(?)	A part of the andesite and basalt intrusions of this region.
Miocene	Vigo	Shales and sandstones.	(?)	Badly disturbed in region of seep.

A generalized cross section (fig. 15) will further elucidate this table.

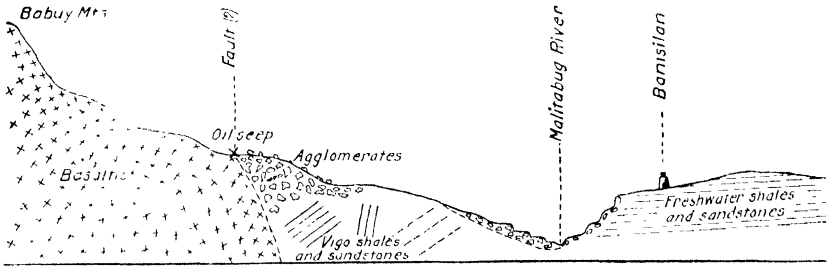


FIG. 15. Generalized geologic section east and west through Pidatan oil seep, Cotabato, Mindanao.

ECONOMIC DEPOSITS

Petroleum.—In the section on Petroleum is given an account of a single petroleum seep in this country, on the headwaters of Kirusoy Creek, a tributary of the Malitabug. Owing to the disturbed condition of the formations and the proximity to igneous intrusives, it is unlikely that commercial quantities of petroleum will ever be obtained from the immediate locality. The oil evidently seeps along a fault contact and originates in the Vigo shales below.

Coal.—No commercial coal is known from this region. Presumably, the central part of Cotabato was a basin in which deeper water prevailed in Miocene time, and on the edges to the west near Parang, and to the east also, we would find shallow-water sediments containing coal deposits. Coal is known in eastern Mindanao outside Cotabato Province and farther west on Sibuguey Peninsula, as already pointed out. Very little prospecting had been done in central Mindanao until 1921, for the very good reason that it has not always been safe for the prospector.

Road metal.—The coral limestone in the hills near Fort Pikit is being used for road metal and is excellent, as would be expected. The limestone in Constabulary Hill is very fine, with but little magnesia; it is nearly white and inclined to be slightly pinkish. It contains numerous Recent marine fossil shells. Among them are the following genera: *Pecten, Conus, Oliva, Turbo,* and *Cypraea.*

Soil.—As most of this district is covered with transported soil (the rich alluvium of the Rio Grande), there can be no

richer agricultural tract in Mindanao, and it should be capable of growing almost any kind of tropical crop.

TIRURAY DISTRICT

Little is known of the geology of Tiruray district,* which lies south of Cotabato River. Very few people live in the region and they are of the lowest station in life. Some of the peaks in the central part of the district, particularly Mount Lubuagan, 1,220 meters, appear to be old volcanic cones.

APO DISTRICT

This district consists of an irregular, interrupted chain of old volcanoes, east of Cotabato district. Mount Apo, approximately in the center of the region, is dominant. Mount Matutum, about 80 kilometers south, and Mount Magolo, between the latter and Apo, are other prominent peaks. The range north of Mount Apo is still largely unexplored, only one or two white men, as far as I know, having crossed it. The journey from the junction of the Rio Grande to Kabakan River south of Mount Apo and to Digos on Davao Gulf was continually in jungle that afforded very little opportunity for studying formations. Occasionally, small outcrops were seen in the stream beds, but no large section or extended exposure was noted. The formation is largely sandstone, with andesite as a capping over much of the country. Several low hills, far apart, are encountered just before the Apo Range is reached; these are marked on the map as the Matutum Range. Neither of these ranges is so well defined as the usual maps indicate. In fact, it is possible to go from Cotabato to Davao without reaching an elevation higher than 610 meters.

There is a sharp difference between the peoples, and also the vegetation, on the two sides of the Matutum Range. West of it are Moros, and the country is heavily forested and very wet at certain seasons of the year. East of it there are no Moros but, instead, a number of tribes, such as the Bagobos, Manobos, and Atas, all quite distinct from the Moros. The vegetation is scantier, the trees are smaller, there is no underbrush, and the climate generally is much drier. Mount Apo could not be seen in passing along its base, because of the constant clouds enveloping the peak. In fact, from the time we left Cotabato until we reached Digos on the gulf ten days later, we had not had a single glimpse of the mountain.

* Mr. G. B. Moody has been in this country recently, but his information is not yet available.

The rock constituting the peak of Apo (Plate 31) is a flow of andesite porphyry, while that coming from the large crater to the northeast is andesite breccia. One phase of this rock found at the summit is an augite andesite. The principal phenochrysts are large, glassy though much corroded plagioclases and colorless augites, with a small amount of biotite mica. Most of the groundmass is fine-grained with small scattered fragments of feldspar, pyroxene, and magnetite.

In ascending Mount Apo three fumaroles were passed at an elevation of about 2,120 meters; these are located along a deep crevasse which cleaves the southeast side of Apo. There is another fumarole about a half kilometer farther west. They are all small, the openings being only a few centimeters in diameter; steam and sulphur fumes issue to a height of several meters with considerable noise. A small cone of sulphur, in some cases a meter high, has formed around each vent. The sulphur is pure and of a beautiful yellow color. It is doubtful if there is a commercial quantity of it, and even if there should be it could not be transported without three days of most strenuous climbing to reach this point on the mountain and two days for the return to the coast.

The difference in the character of the material on Mounts Apo and Pumantigan is well seen in the cañon of Sibulan River. The formation here is a volcanic agglomerate, the rock being andesite, but in irregular bowlders in a volcanic matrix. In one place the walls of the cañon change above into a solid flow of andesite. Presumably, these zones are repeated many times before the top of the cañon is reached. It seems evident that there have been tremendous explosions from the crater, of which Mounts Calelan and Pumantigan are the highest points.

I know of no economic deposits in this district, aside from the small amount of sulphur, but the country is practically unprospected.

On April 28, 1911, Maj. E. R. Heiberg and party made the ascent of Mount Matutum, which is the next highest point in Mindanao and is situated between Mount Apo and Sarangani Bay. He found the elevation to be 2,402 meters. Samples collected at about 2,000 meters elevation and submitted to me proved to be andesite. Major Heiberg says in his report:

> The peak is perhaps 20 feet in diameter and (with the exception of some scrub growth about 6 feet high) was, fortunately for us, quite bare, enabling us to obtain an unrestricted view in every direction whenever the floating

clouds below permitted. I had taken a large camera along, but was forced to leave it behind with the cargadores.

The perimeter of the extinct crater consists of four distinct peaks (one double), and averages about 350 yards in diameter. Carter and I made several attempts to descend into the crater, but finally gave up on account of its precipitous sides, the ropes I had brought along being abandoned when the cargadores gave out. We were enabled, however, to get a good view of it, and to observe that every portion is covered with the same peculiar dense growth described above. It is about 400 feet deep, and apparently three gorges which cut in between peaks prevent the formation of the lake containing deep-sea fish and white crocodiles which the legends of the superstitious Bilanes described. The volcano has been extinct (the literal translation of Matutum is "has burnt" or "fire out") for a century at least, although Lieutenant Mosher reported from Makar, under date of March 31, 1911, that, "on March 6 severe earthquakes were felt at about 11.30 p. m.; the following day, March 7, Mount Matutum was smoking freely. Severe earthquakes were again experienced on the 22d." Just before we left, a large fire was built, the smoke from which, as we learned afterwards, was seen for many a mile. There is entire absence of rock on the very top, and all of the cone above approximately 6,000 feet elevation (except, of course, the vertical and overhanging walls) is covered with a peculiar vegetable loam. The huge outcroppings of rock—the precipices heretofore mentioned—are in two colors, gray and red; both resembled granite in appearance, but the gray is soft and not unlike pumice.*

Samal Island.—I have never been on this island, but I have a specimen of the limestone which is said by Dr. H. N. Whitford, formerly of the Bureau of Forestry, to form the capping of many of the higher points of the island. This limestone is white and quite pure, and presumably is Malumbang (Pliocene).

AGUSAN-DAVAO DISTRICT

Agusan district lies between Apo Range and the eastern cordillera.† Davao is the principal town in its southern part and is the headquarters for the numerous abacá plantations bordering the gulf of the same name. My knowledge of this region ends with Davao, as at this point I left the exploring party. The town is on a narrow stretch of coastal plain between Davao and Lasan Rivers. Remnants of what appear to be marine terraces (although they may be entirely river formations) occur a short distance from the settlement. There is one distinct terrace which is from 15 to 30 meters above the sea. I saw no fresh rock exposures, but the streams are full of pebbles, mainly of andesite, which evidently have been transported from the Apo Range. Published geologic knowledge of Agusan Province

* A specimen submitted was determined by me as andesite.—W. D. S.

† Somewhat more country is embraced here than comprises Agusan Province.

consists almost entirely of observations by Montano and by Goodman(299) and Ickis, who made the trip from Davao to Butuan overland.

In this chapter will be added my translation of notes by Montano,(447) who was in the Philippines from 1879 to 1881 and who gave some attention to the geology of Mindanao, as follows:

All the facts that I have been able to observe in the interior and along the coast of the eastern part of Mindanao tend to prove that this region has emerged for the most part since the older epochs, or has undergone in the Miocene epoch an uplift which continues to this day. In following the course of Sahug River, one cannot at first have any idea of the geologic constitution of the soil, because in the lower reaches of the river there is a deposit covered with a thick bed of humus. Higher up, the bed of the river is less deep and shows a number of rapids formed by considerable blocks of rock. The rocks which constitute these outcrops belong to several species, quartz porphyry (porphyry petrosiliceux), melaphyre, and compact white and crystalline limestone. At 7° 40′ north latitude, that is to say, about 35 kilometers in a direct line from Davao Gulf, the bed of Sahug River is covered with enormous blocks of corals which, according to the section I secured, belong to the genus *Astraea*, very much like species now living in Davao Gulf. At several points where I could make out the composition of the mountains, these are formed of calcareous terraces, which appear to be horizontally stratified. In the center of [this part of] Mindanao, Mount Hoagusan separates the basin of the Sahug from that of the Agusan which empties into Butuan Bay in the northern part of the island. Tubuan, an affluent of the Agusan, has its source on Mount Hoagusan at about 270 meters altitude. At this point one finds melaphyres. The banks of the stream show beds of plastic clay with concordant stratification, dipping to the north at an angle of 45°. The larger part of the stream bed is formed very extensively of calcareous terrane, which at several points comes up in vertical masses from 20 to 40 meters in height. Upon the right bank of Agusan River north of Lake Dagun, or Linao, about equally distant from Davao Gulf and Buluan Bay, is Mount Banauan, the altitude of which is 240 meters above the level of the sea and approximately 210 meters above the plain, which extends from its foot toward the south. It seems entirely formed of andesite which occurs in blocks of from 10 to 20 cubic meters. This same kind of rock, though altered, is found in Banauan River, which flows at the foot of the mountain. The andesites have been analyzed by Monsieur Ch. Velain, Maitre de Conférences at the Sorbonne.

The banks of Agusan River from Mount Hoagusan to the sea are covered with forest; hence, still less is known of the nature of the rocks lying below. Near the confluence of the Mahassan upon the right bank of the river, there is a promontory of some meters elevation which is made up of beds of stratified clay dipping 45° to the west. Between Las Aevis and Butuan the left bank is made up of altered diorite in peperin (tuff), stratified and dipping to the east at an angle of 20°.

Agusan district, then, consists of two principal divisions: The southern part, which is mountainous and in which the streams are swift and full of rapids; and the northern, which

is largely low plain, with large, more or less sluggish streams and few rock exposures. Of some fossils that he collected at Maasin, Goodman says:(299)

> An estuary leading into a small pond which drains into the Agusan is situated at a place called Maasin, about 3 kilometers south of Veruela. An outcrop of soft, blue shale, containing a large variety of fossil shells in an excellent state of preservation occurs on the west bank of this estuary.

These fossils were sent to me at Leyden, Holland, for study and comparison; they proved to be marine Pliocene or early Pleistocene. Similar fossils were also found at San Rafael on this river. Some of the species are *Venus squamosa* Lam., *Tagalus coarctatus* Gm., *Arca nodosa* K. Mart., *Ranella subgranosa* Beck., and *Turritella cinquelifera* Sow. This find proves that the sea came thus far into the interior at that time.

Economic deposits.—Mr. John S. Garvan, formerly of the Bureau of Science, who is thoroughly acquainted with this region and its inhabitants, informed me that gold was panned in paying quantities by the people of Cansuran district, in neighboring mountains to the west, and in the headwaters of Solibao, Adlayan, Bunauan, and Hinatuan Rivers. Gold is reported also from Bilay, Masago, Ua-Ua, and Culi Rivers and from the Quila near Guadalupe. Coal has been found on Ua-Ua, Culi, and Bunauan Rivers. These deposits are referred to under Surigao. The gold deposits and late operations in this region are discussed in the chapter on Economic Geology.

Some prospecting for petroleum has been carried on in this district, but no important announcements have been made. It is not at all improbable that in the Pliocene estuarine deposits, in the valley region proper, accumulations of petroleum may be discovered.

There are practically no roads in the province, and this, coupled with the paucity of rock exposures, makes it extremely unlikely that the Agusan district, in the northern part at least, will for some time to come be of any importance as a producer of mineral. There should be some excellent transported clays in this valley, which might be utilized.

SURIGAO DISTRICT

In the Surigao district the cordillera in the extreme eastern part of Mindanao Island, continuing into Davao, is included. Our knowledge of the geology of the rocks of this region is extremely limited. Goodman has crossed it to the south, in the

vicinity of Mati at the head of Pujada Bay. He found the ridge to have a core of igneous rock which had undergone some metamorphism. The original, unaltered diabase, which seems to be the commonest rock encountered, presents a typical ophitic structure and contains, in addition to the feldspar and ferromagnesium minerals, a considerable proportion of secondary quartz and microscopic crystals of apatite. Goodman also found a chloritic schist, reddish brown in megascopic specimens (also containing a large amount of secondary quartz), which he considered to be an alteration product of the original diabase. He says that both coasts of the peninsula are composed of sedimentary strata. A pink limestone, intersected by numerous veinlets of calcite, rests on the west flank of the igneous intrusion, while the east coast is mainly conglomerate and brown shale. The beds at Mount Badas attain a thickness of over 180 meters and dip about 45° toward the southwest. In the vicinity of Mount Mayo the formation is sedimentary. Goodman found the conglomerate here dipping at an angle of approximately 30° east. The bowlders in the conglomerate are igneous. At a place called Lucatan, about midway between Mayo Bay and the town of Tarragona, the conglomerate is unconformably overlain by limestone, which is merely an elevated reef.

Goodman found a seam of coal about 85 centimeters thick on the south bank of Cotabato Creek about 9 kilometers north of Tarragona. The seam dips at an angle of about 15° southeast. A conglomerate of coarse sandstone immediately underlies it, while above is a soft, brown shale which, in turn, is overlain by an impure limestone. This coal is subbituminous, and in general appearance is much like the other coals of the Islands. Goodman considered this a favorable point for further prospecting.

There is little information about the east coast. A series of specimens given me by Father Francisco de P. Sanchez, a Jesuit missionary who was stationed at Baganga for many years, includes lepidocyclinal limestone of a beautiful pinkish color (evidently the same formation as was found by Goodman farther south), specimens of silicified wood, and a rock made up of many coral stems, all completely silicified. Specimens which simulate the petrified bones from the flipper of a cetacean also appear in the collection. The likeness is very remarkable, but these specimens are clearly not petrified bones, the phenomenon being due simply to the differential wear of alternate hard and soft layers from a calcareous formation. It is evident

that there is considerable residual limestone left on the hilltops on the eastern flanks of this cordillera. Specimens of andesite are also to be found on the beach at Baganga.

The next point at which Goodman touched is Bislig, at the head of Bislig Bay. On his way from Agusan River to Bislig, he encountered much the same formation as he had seen farther south. He examined a coal deposit a short distance up Bislig River, but did not learn much about it. It is of considerable importance to know that coal outcrops at two distinct points on the east coast.

Montano has left a few notes regarding the east coast of Mindanao. He says:

> At the center of the island between Bislig on the map shown and the Rio Simulao, a tributary of the Agusan, I crossed the central cordillera at an altitude of 130 meters by the passage of Mount Bucan, the formation of which is made up of a thick bed of brown clay, but at the foot and to the west of this mountain the Miaga, a tributary of the Simulao, has some cascades and rapids which reveal massive Miocene andesites of great thickness. The east coast of Mindanao between Bislig and Pujada Bay presents a succession of capes generally elevated and rounded and formed by the projecting spurs of the Cordillera Central. Between Bislig and Cateel upon this coast I collected some madrepores altered at the contact with serpentine. It is along this part of the coast that elevation seems to be most evident. Some large banks of madrepores rest above the level of the sea, occurring as large horizontal tables polished by the waves which the northeast winds raise above their normal height. These banks of madrepores are especially prominent between Cateel and Point Bagoso. They are without doubt of the same origin as those produced by the waves between Bislig and Cateel, which in bad weather are dangerous to approach. These rock breakers form a cordon parallel to the bank upon which the sea dashes with fury, although a relative calm exists in the zone they protect. Particularly along this coast, and even more so between Point Bagoso and Pujada Bay, the evidences of uplift are manifest. One finds there all gradations between the broken madrepores mixed with humus upon the summits of the capes and those which, raised at the edge of the coast, have lost their organic material only recently. Upon the same coast one finds at every step some conglomerates which are formed by a mixture of sand and débris of ground-up mollusks and madrepores. In the Gulf of Mayo, near the Bay of Pujada, the cliffs of Butuan, which are quite extensive and have an elevation of from 20 to 60 meters, are formed of pudding stone in which mollusks abound similar to those which live to-day in the gulf. I have collected some madrepores and some gypsum mixed with pyrites of iron upon the coast of the Bay of Pujada, and upon the ridge which separates it from the Gulf of Davao, some brecciated quartz.

It is evident from these notes that the usual stratigraphic sequence in the Philippines is found in this district. However, as this part of Mindanao is nearer to the true cordillera and

therefore an older portion of the island, the sediments would be of shallow-water origin, so one would expect to find coal instead of oil deposits.

According to further notes by Goodman the rocks in the eastern cordillera (known as the Diuta Mountains) consist of a hornblende diorite and metamorphic rocks, chiefly chlorite schists. A finely laminated mica schist with a high percentage of calcite is also abundant.

Goodman has discussed the origin of Lake Mainit as follows:

Lake Mainit is frequently spoken of in the literature as a crater lake, mainly I suppose, because of its location, outline, and proximity to the extinct volcano Mainit. However, from my own observations I believe that the lake was caused by a subsidence of the submerged area, consequent upon the withdrawal of the material which went to make up Mount Mainit and other volcanic masses to the north. I did not visit the east shore, but Montano reports the presence of hot springs emanating from limestone strata, but I crossed the narrow ridge separating Lake Mainit from the Surigao Sea and there also I found nothing but stratified rocks in their original or metamorphosed condition. Most of them were chlorite-bearing schists or alteration products of the same. The original bedding planes are obscured by the new cleavage planes induced by dynamic pressure. In general, the direction of the cleavage planes is somewhat west of north, while their inclination is in both directions east and west. The east flank consists largely of red and brown slates finely laminated, and in places interleaved with white marble. Near the top of the ridge the proportion of calcite increases, and some fine pieces of marble are to be observed. Inclusions of a green micaceous mineral, probably chlorite, are very common. The slate is highly calcareous and is probably an alteration product of an impure argillaceous shale. It has a very fine and distinct cleavage, and if sufficient material can be found and conditions of demand and transportation were favorable a quarry might be opened here for the production of roofing slates.

The west slopes of the ridge consist largely of talc-schists, while on the east flank chlorite schists predominate. In places the latter are altered to talc-schists. Large masses of red jasper are also to be found, particularly in Sagay Creek. None of the numerous pans of river gravel which I washed during the traverse across the peninsula showed any colors.

I left the town of Jabonga in a small boat and, because of exigencies of the weather, had to put ashore two or three times, and was thereby enabled to determine the geologic formation of the west coast of Lake Mainit to be very similar to that of the ridge between the lake and the sea, that is, calcareous shale and chloritic schist.

North of Lake Mainit Goodman encountered limestone, basalt, and andesite. Of this he says:

The igneous rock has been largely disintegrated and the trail passes mostly over a red residual clay with traces of *large*, weathered feldspar phenocrysts of the andesite.

A few kilometers east of Goodman's line of march lies the great deposit of lateritic iron ore later discovered by H. F. Cameron and examined by Pratt and Lednicky.

Economic deposits.—Gold has been mined by Filipinos in this region from time immemorial and there have been several ventures in placer on a large scale by white men, but to-day only one dredge, at Lianga on the east coast, is operating.

Large iron deposits in the extreme northeast corner of Surigao have been discovered and surveyed, but no ore is mined. More details with reference to these deposits are given in the chapter on Economic Geology.

Of the geology of the region where the large deposit of lateritic iron ore mentioned above was discovered Pratt and Lednicky, who reported on it for the Government, say:(504)

The iron-ore deposit covers a region which attains only moderate elevations, but is of sharp relief. Mount Legaspi, elevation 1,170 meters, is the highest point included within the boundaries of the iron-covered territory. Other peaks near the western edge of the deposit are as high as from 500 to 700 meters. The region slopes from Mount Legaspi eastward and northward to the coast, but the slope is by no means regular or continuous. The country is deeply incised; even the smaller streams flow through deep and precipitous valleys. This is a result of the exceedingly heavy rainfall between the months of October and March. The weather-recording station at the town of Surigao shows an average annual rainfall of over 3,000 millimeters, most of which occurs during the above-stated months. The hills rise abruptly from the coast, and much of the coast line is marked by sea cliffs. The outline of the coast is fairly regular, but is broken by several prominent points and bays.

Only two rivers of any size flow across the iron-ore deposits. One of them, flowing north, discharges its waters into the sea at the barrio of Taganito; the other drains the eastern flank of Mount Legaspi and flows to the south, reaching the sea at Carrascal. Either of these rivers could probably be made to yield a fair amount of water power, but no data are available on their volumes.

GEOLOGY

The iron ores are clayey residual products from the surface decomposition of igneous rocks. They are similar to the laterites in origin found commonly in tropical countries. The parent rock in Surigao is subsiliceous in character and is probably a peridotite, but wherever exposed it is so completely altered as to make the determination of its original character difficult. The outcrops which are most widely distributed consist essentially of serpentine. On the beach, throughout the length of the deposit, rocks of other types are found locally and probably occur as dikes cutting the main rock mass. The dike rocks include diorites, gabbros, and felsitic to porphyritic andesites. Schist has also developed locally, probably in shear zones, and occurs in rare fragments along the beach.

Sedimentary rocks, principally tuff-sandstone and crystalline limestone, overlie the igneous basement, the alteration of which has given rise to the

iron ore, and the line of contact between the basement rocks and the overlapping sedimentaries marks the limit of the ore deposit toward the interior. The sedimentaries outcrop on the coast at Capandan southeast of Claver Point, and the line of contact between them and the ore deposit runs south-southeast. Blocks of limestone are found resting on the ore formation on the hill southwest of Capandan. Judging from the character of this limestone, the sedimentaries are probably of Miocene age. An escarpment marks the edge of the sedimentaries and forms a prominent line of hills trending south-southeast back of Capandan. The sedimentary rocks appear on the coast on the southern edge of the ore deposit in the ridge at Carrascal, the line dividing them from the ore deposit passing westward beyond Mount Legaspi. Thus the heavy, broken line which delimits the ore deposit in Plate I marks, also, the line of contact between sedimentary and igneous rocks throughout most of its course. The line approaches more closely to the summit of Mount Legaspi, however, than do the sedimentaries to the west, because the upper slopes of this peak show very little ore. It recurves, also, at its southern extremity to separate the area of alluvium around Carrascal Bay from the iron-ore formation. The numerous small islands which lie off the coast between Capandan and Carrascal are all composed of sedimentary rocks, except Ludguron Island in Carrascal Bay, which is partly covered with iron ore.

CHARACTER OF THE IRON ORE

The ore is principally ferruginous clay, but contains also an abundance of small, round pellets of hydrous iron oxides, as well as fragments or crusts of the parent rocks, much altered, porous, and iron-stained, but maintaining their original form. Mineralogically the ore is probably a series of hydrous iron oxides related to limonite. The surface of the deposit is a deep reddish brown, almost crimson at places, but beneath the surface the color is lighter—a yellowish brown—while the transition stage between the ore and the underlying rock is pale green. The thickness of the mantle of ore varies irregularly up to a maximum of about 20 meters. The ore in place is soft and very spongy or mealy. In walking over it one often breaks through the crust into small openings or cavities beneath the surface.

This ore is quite like the formation described by me in 1906, from the eastern end of Batan Island, near Luzon.

Goodman found traces of poor coal also in the region of Tagbunuan Creek. The deposit has never been developed and, judging from his description of the geology of the vicinity, development would not be justified.

BUKIDNON DISTRICT

In the physiographic part of this chapter mention of Bukidnon has already been made and some data have been given concerning the rocks of that region.

There now remains to be considered the subdistrict of Cagayan. This is an irregularly defined area, bounded on the west by Iligan Bay, on the north by Macajalar and Hingoog Bays, and

on the south by the upland country of the Cotabato district. A stretch of unknown country extends to the east of this district, through which Ickis had traveled and concerning which he made notes just before his death. The district is marked physiographically by a limited coastal plain, a rough but not very elevated interior, and several rivers (Cagayan, Iponan, and Tagoloan), which head on the divide close to Pulangi River. The country rock consists largely of sedimentaries and a schist formation partially overlain by andesite. The reader is referred to a translation of Abella's(576) report of 1877 for a detailed account of this district. This report deals with the high- and the low-level placers of Iponan, Cagayan, and Tagoloan Rivers. According to Abella, the country rock is largely a chlorite in which small stringers of quartz-bearing gold occur. These stringers are too small to be worked per se, but the concentrates which have been deposited along the rivers already named can be worked. The local inhabitants have probably worked these placer deposits for ages and have become so skillful that they are able to tell at just what depth they will get values. The operation is rather crude, and consists in washing out the rich spots and panning the concentrates.

In another paper, published about the same time as the report just referred to, Abella gives some further information regarding the geology of this country. He refers to a number of formations, which will be taken up here briefly.

He noted a considerable limestone formation which apparently is overlain by a conglomerate with a calcareous matrix. This conglomerate he calls "gonfolita;" above the gonfolita he encountered a yellow marl, fairly loose and quite like that which covers the slopes of the divide between Cagayan and Iponan Rivers. This marl is probably the result of the weathering of the matrix of the conglomerate. The pebbles of this conglomerate, according to Abella, are serpentine, argillaceous slates, and trachytic rocks of many types. He also found an arkose (*macino*) and an impure sandstone formation which he termed "molasa." The limestone of this country is cavernous and has abundant stalagmites and stalactites. Abella found he was unable to determine specifically one fossil which he found, but he believed it to belong to the genus *Turbinolia*. On the basis of this and lithologic evidence, he classified the limestone marls, conglomerates, etc., of this region as Miocene, which I think is reasonable. Upon the hills near the barrios of Munique, Quiliut, and Tagiptip, he found some white bowlders of cellular structure.

At first he thought these were limestone, but on closer examination they appeared to be of a feldspathic material with secondary crystallization in the pore spaces, probably zeolites, and with all the other characteristics of modern volcanic rocks. To explain the presence of these rocks, Abella suggested that in the mountain chain to the south and southwest there existed a crater which at a former period threw these volcanic bombs over the country. He also noted a very important feature; namely, that there is a lineal regularity in the volcanic manifestations, as the line connecting the recent volcano of Camiguin and of Apo and Batulong passes through this region, and he thought this confirmed his supposition. Abella's general conclusions regarding this region were as follows:

First.—There appear to be only three distinct formations; shales, more or less metamorphosed; marls; and alluvial deposits.

Second.—The metamorphosed shales or "slates" constitute the oldest formation in the region.*

Third.—The placers are classified as ancient and recent.

Fourth.—There are apparently no metalliferous deposits other than the gold.

Some occurrences of gold have been reported southeast of Nauan, but they have not been investigated by Abella or by any of the later engineers except Mr. J. Clayton Nichols,(459) who visited this region in 1900 in a private capacity. His report has added very little new information about the geology. His conclusions regarding the possibilities for mining are, however, of interest.

The gold production of this region can only be estimated, as the Filipinos sell most of their finds to local Chinese traders, and it never passes through the hands of any official. Eight thousand pesos are said to have been taken from one hole and 5,000 pesos from another.

Ickis published a report which is interesting on account of the confirmatory evidence of volcanism in this region as well as the data he obtained regarding the country farther south, in the vicinity of Sevilla, on the upper waters of the Pulangi, much farther interior than either Abella or Nichols ever reached.

The physiography of Tagoloan River is discussed in another chapter. The main point of interest in this connection is the fact that after the gorge of the Tagoloan is passed, some 25 kilometers from Agusan, the country opens and is much gentler in topography.

* These are pre-Tertiary and, presumably, Mesozoic in age.—W. D. S.

Ickis found only alluvial land covered with talahib (*Saccharum spontaneum* Linn.) in the region of Pulangi River. This land contains a great amount of gravel and, according to Ickis, is of considerable area. He thought the country would be well adapted to dredging operations. He says:

> The gravel beds along Pulangui River are extensive, and promising colors were obtained by washing the surface near Sevilla in gold pans. It is believed that these gravels are worthy of careful investigation by prospectors who have testing machines, or who are equipped to sink test pits. The head waters of this river also afford a virgin field, since no prospector or miner has ever been known to visit the region. Gold is known to occur in the river gravels and the rock is of a nature favorable for the formation of mineral deposits. At the present time transportation is a difficult problem, but it is expected that a wagon road will soon be constructed from Agusan to the Pulangui River.

In the chapter on Volcanology, reference is made to Catarman Volcano on Camiguin Island. One sample of the rock from the mountain, collected by H. D. McCaskey, is a grayish, vesicular lava with numerous glassy feldspar and a few ferromagnesian phenocrysts. Occasionally holocrystalline patches are seen in the rock. Still another hand specimen is a hard, dense andesite, which doubtless came from an older part of the mountain.

This brief summary gives the essentials of our present knowledge of the geology of Mindanao. We have only an incomplete reconnaissance of this vast region, which it is hoped and fully expected will not be far behind the other parts of the Archipelago when it is developed.

BASILAN

Basilan, a short distance from Zamboanga, contains extinct volcanic cones and hot springs. Several rubber plantations are doing well on this island. There is a good harbor at Isabela. This island is discussed under the Zamboanga district, pages 220 to 226.

CAGAYAN SULU

Guillemard(302) has written a very interesting general account of the crater lakes of Cagayan Sulu. He speaks of a number of circular basins filled with water, which he thinks represent the craters of extinct volcanoes. Beyond this he gives no geologic data, but he has published a map of the island with additions and corrections by Lieutenant Powell, of the Royal Navy, and himself. This map shows as many as fifteen peaks in the interior, the highest of which is 253 meters, which evidently represent extinct volcanic vents; and in the southern part of the island three almost circular depressions, two of which are

entirely inclosed, and the third, Lake Jiwata, is connected with the sea by a small opening. In this opening are two or three islets, and it is quite evident that this basin was also once entirely inclosed, its narrow rim having been broken through by the sea.

SULU ARCHIPELAGO

A host of small islands, rising above a submarine bank which extends to Borneo, lie southwest of Zamboanga Peninsula and in the same tectonic line. The largest of these are Jolo, Tawitawi, Pangutaran, Siasi, and Sibutu. There is very little published information concerning this region, and only two geologists have left notes on the subject. Montano devotes one paragraph to this Archipelago; it reads as follows:

> The Archipelago of Sulu extends from Borneo to Mindanao in a chain of islands situated upon the summit of a submarine bank. Without doubt several of these islands with a slight elevation consist in great part of banks of corals which gradually reach the surface of the sea, and which, becoming covered with detritus of various kinds, are covered with vegetation. This is especially true of many islands, and notably of that of Sulu, which gives its name to the Archipelago. In the Island of Sulu I have not observed signs of a coral formation except upon the coast and it occurs here homogeneous and formed of a mixture of madrepores and molluscs. It seems to rest upon sand. Its upper level is raised about 2 meters above the highest tides. The mass of the island seems to be of volcanic structure. Some deep trenches opened in the hills near the Spanish village of Sulu (Jolo) show numerous blocks of lava containing pebbles. Some larger blocks of the same rock are scattered over the plain and are seen in abundance in the beds of the streams as well as near the ravines made by the rain which comes down from the summits of the island. Especially characteristic is the great development of weathered material covered with cogon prairies or forest which conceal the structure of the formation.

My observations in Sulu consist of a trip across Jolo Island from the town of Jolo to Meimbun; the ascent of Mount Dajo; some reconnaissance on the outskirts of Jolo; a short trip of 4 or 5 kilometers on the coast of Siasi Island; a short excursion of a few hundred meters from the coast on Lapac Island; an ascent of the high peak on Bongao Island; and such observations as I could make from the launch which skirted many of the small islands on the trip through the archipelago.

The striking feature about this little archipelago is of course the multitude of islets with innumerable little bays and proportionally great length of coast line. These features make this one of the best possible resorts for pirates, and hardly a year passed, until recently, in which the United States troops did not

have some slight encounters with them. However, piracy has now practically ceased.

In the Sulu Archipelago volcanism has played a very prominent rôle and for the most part is of more recent date than that in Mindanao.

Jolo Island, as far as I could see, is almost entirely blanketed by volcanic material, either basalt, tuff, or loose ash. I saw no active volcanoes in Jolo, but it is reported that there are hot springs at Siit Lake. The island is studded with extinct or dormant cones, the most prominent of which (and at the same time most interesting from a historic standpoint) is Bud Dajo, 10 or 11 kilometers southeast of the town of Jolo. This is a beautiful cinder cone now covered with luxuriant vegetation. The diameter of the crater is about 500 meters. It is almost circular and is broken down on the southeast side, where a small stream issues. The stream is fed by a spring that is almost in the center of the crater.

It would be extremely desirable to know the nature of the formation below the mantle of volcanic material. The streams as yet have not cut very extensively, so that it is not known at what depth the sedimentary formations are to be found. However, should sandstones and shales not be found, it is quite reasonable to suppose that drilling in the vicinity of Jolo would tap a loose formation of volcanic material which carries water. I know of no deposits of economic importance on this island.

In none of these islands is there any distinct cordillera, but numbers of more or less isolated cones exist which do not appear to have even linear arrangement, although more-detailed survey might reveal some system. Subsequent erosion has produced in these islands a topography which is peculiar and very pleasing in its long, gentle slopes and beautiful curves. On Jolo especially there are many of these worn-down stocks having the shape of saucers turned bottom up, with a decided sag in the bottom. Jolo is only partially wooded, there being long stretches of fields covered with cogon, with here and there cleared patches on which the industrious Moro has cultivated the tapioca plant. The soil is deep, rich, red, and exceptionally fertile.

On Tawitawi the signs of recent volcanism are not so pronounced, and from what I have seen this island is largely made up of sedimentaries. I made the following notes while passing close to Tawitawi Island:

I saw no signs of vulcanism on the island. There are few high points; in fact, the sky line is much like that of northern Cebu. A forest fire in

1903 decimated the forest and now there is nothing but straggling timber and thick undergrowth. We skirted the northern side of the island. Tawitawi Mountain may be volcanic, but old. A white rock outcropping on the side of this mountain is seen with a glass. It may be limestone.

Siasi and Lapac Islands are, as far as known, covered with a mantle of volcanic material weathered to a considerable depth. Bongao Island, at the extreme southwest end of Tawitawi, is made up largely of tilted beds of sandstones and conglomerate. Vertical jointing in Mount Vigia simulates the columnar jointing of basalt; it is only upon close examination that the formation is found to be not volcanic. I ascended Mount Vigia and found it to be conglomerate from top to bottom. The matrix is a well-stratified sandstone, very ferruginous in places, and dipping southwest at an angle of approximately 15°. The bowlders of the conglomerate are andesite, varying in size from pebbles to masses weighing several tons. At the edge of the town and but a few meters from the sea, at an elevation of 12 to 15 meters, there is a small shell bank, partly coralline. The shells are very recent. With the exception of Mount Vigia, which owes its height to the resistant material in it, the island is low.

On Marongas Island just north of Jolo there is an exposure of conglomerate which is cut by more or less vertical basalt dikes. These dikes vary from a few centimeters to a meter in width. On either side of the dikes the rock has been vitrified for several centimeters. Examination of the dike rock under the microscope shows a very fine-grained lava with distinct flow lines and phenocrysts. The phenocrysts are olivine and plagioclase feldspar. The streaks, which have a fluxional arrangement, consist of a very dense cryptocrystalline mass in which innumerable minute magnetite grains occur. There is a rude parallelism of the crystals bordering these denser streaks. The rock is very vesicular in part. The hummocks on this island and on several others are simply due to the hard conglomerate and dike formations.

According to Merrill, the long narrow island of Sibutu is merely a raised coral shelf just above sea level and is perfectly flat except for one hill in the center.

The geologic history of the Sulu Archipelago, briefly stated, is about as follows: A submarine bank, which may represent a mountain or an upthrust fault block, rose out of the sea, with alternate periods of submergence and elevation. Corals grew upon this platform, and at several points volcanic flows and fragmental material, such as tuff, were spread over the country.

The period of greatest activity was probably in the Pliocene and Pleistocene. At this time there may have been a continuous land bridge between Mindanao and Borneo by way of the Sulu Islands. Then followed disruption due to subsidences, as indicated by atolls, and the bridge was broken. Volcanic activity in some quarters certainly continued until recently. The weathering of the volcanic formations has produced a heavy, ferruginous deposit not unlike the laterite of India.

I know of no deposits of economic importance being worked in the Sulu Archipelago. Petroleum seeps have been reported from Siasi, but nothing authentic can be said of them. It would be astonishing if any genuine seep existed on this island.

Atolls.—There are a few more or less perfect atolls in this region, some with lagoons of considerable size in the center, others with only shallow depressions, due either to elevation or to filling of the basins, or to both. Atolls are not common in the Philippines; the reasons for their scarcity have been discussed by Davis.(188) Examples of atolls in this region are the Taja-Zan group, northwest of Tawitawi Island; Simalue, north of the east end of Tawitawi Island; and Tara Island, north of Siasi. I have made no study of these. The coral reefs of the Philippines afford an almost virgin field to the investigator. It is regretted that our economic work has not permitted us to make some contributions along this line.

Sea stacks.—For want of a better one this term is used to describe a very small island, Marongas, just north of the town of Jolo. It is little more than a bump standing out of the sea, and its sugar-loaf shape is due to hard, resistant, basalt dikes which have intruded the sediments causing the whole to resist erosion. Other small islands in this region are probably of similar origin.

Crater lakes.—There are several crater lakes on Jolo Island. Siit Lake, near the constricted portion of the island, is particularly noteworthy. However, by far the most striking of these lakes occur on the southern side of Cagayan Sulu, where there are three that are almost circular in form. They are so near the seashore that the sea has broken through the rim of one of them.

PALAWAN-CUYO-MINDORO GROUP

This group comprises, among a host of smaller islands, the following chief islands, beginning at the extreme southwest,

near Borneo: Balabac, Palawan, Culion, Busuanga, Mindoro, Lubang, and the Cuyo subgroup.

Relation to other parts of the Archipelago.—This group is a distinct portion of the Philippines and is related to Borneo more closely than to the remainder of the Archipelago. An earlier chapter shows how it is tectonically related, and Worcester(651) has shown that, zoölogically, the connection is very close. According to Merrill, there is a Bornean flora which comes through Palawan to the west side of Mindoro but does not cross to Luzon.

Whether Palawan, Cuyo, Balabac, and Mindoro represent the high points along a partly submerged mountain range, or are due to faulting, I cannot say, but I suspect that a combination of these two would be near the truth. A study of the hydrographic charts of the region suggests faulting, on the west side at least, as there is a line of deep soundings that parallels the coast which would seem to indicate that something of this nature had occurred.

Very little geologic investigation, even of a reconnaissance nature, has been carried on in this group. The more-important members of the group will be taken in turn, beginning at the southwest.

BALABAC

This is the nearest in the group to Borneo. In 1913 Prof. Randall A. Rowley, of the University of the Philippines, collected a few specimens from this island and a much larger number from Palawan, but he has published nothing regarding them. The only specimens from Balabac of especial interest were some radiolarian cherts similar to those I had already discovered in Ilocos Norte, Luzon, which are now known from two or three other localities, and *Lepidocyclina* limestone.

The following notes are from a manuscript report by McCaskey:

> In the hills on the south, west, and north sides of Clarendon Bay I found extensive formations of a soft yellow sandstone. This appears to be fossiliferous in part. No other variety of rock was seen within a radius of 8 kilometers of the bay. The sandstone outcrops in buttresses and bowlders and is so massive that the dip and strike could not be ascertained. As coal is reported in northern Balabac and as the strata and formations of the island are apparently not very greatly contorted and folded, this may prove to be the Eocene sandstone found in Cebu with the coal measures.
>
> Copper has been frequently reported from Balabac; but I could find no verification of its existence, although I questioned intelligent residents

who had lived long upon Balabac and have been over the various parts of the island.

Coral reefs extend from the shore of Balabac upon almost all sides, and those of the southwest coast are very extensive and dangerous to navigation.

PALAWAN

Of Palawan we have much more information. About the first reliable data that I received came from the late Chas. M. Weber, a prospector of more than average ability, who sent in many specimens with field traverse notes. Most of his data had reference to the region inland from Puerto Princesa, the capital of the province. From his notes it could be seen that the interior had a core of crystalline rocks, principally schists.

In 1910 Dr. Paul C. Freer made a trip to St. Paul's Bay where he, with others, made a study of a remarkable cave (Plate 27) with a subterranean river which empties into the bay. It is possible to run a launch up this river for several kilometers. Freer collected specimens of the limestone in this cave and secured also some excellent photographs which showed evidences of recent uplift along the coast. I examined the limestones in this section and found that they contained *Lepidocyclina* and *Lithothamnium,* which would place this formation in the upper Miocene.

In 1913 Rowley spent several weeks on the island and made a valuable collection of rocks. He spent most of his time in the vicinity of Taytay, but visited some other localities in this general region. He has published nothing on his work in Palawan. I have examined the collection and have placed all the rock localities on a large chart. As these are too scattered to permit the construction of even a most general map of the island the spot-map plan will be used for this group (Plate 39). The following rock types were found by Rowley on Palawan:

Plutonic rock: Diorite.
Extrusive rock: Agglomerate basalt.
Metamorphic rocks:
- Chloritic schist.
- Graphitic schist.
- Talcose schist.
- Slate.
- Serpentine.
- Quartzite.

Sedimentary rocks: Cherts.
- Conglomerate.
- Shale.
- Limestone.
- Sandstone.

It appears that in the center and in the south crystalline rocks predominate, while limestone is the chief formation in the north. There is likewise a considerable area of basaltic and andesitic extrusives. According to Rowley, a lake near Taytay Bay has been formed by a recent basalt flow cutting across and damming a stream channel.

Although the very latest episode in the geologic history of Palawan is elevation, indicated by cliffs wave-cut well above the storm-wave height, the last great movement was one of submergence, as indicated by the strong embayments along Malampaya Sound.*

Considering the circumstances under which it was made, the best and most remarkable study of recent events in the Palawan region is that by Wm. Morris Davis.(187, 188) This study was made entirely from the admirable Coast and Geodetic Survey charts. Several paragraphs have already been quoted from Davis in the chapter on Physiography.

Economic deposits.—Although some gold has been found in the streams of Palawan, and tin has been reported by Lednicky from the east coast a few kilometers south of Puerto Princesa, there is absolutely no record of mineral production on the island.

Some years ago McCaskey visited Palawan and collected a very large crystal of amethyst, nearly a meter in length, which was sent to an exposition in the United States; it was never returned. According to McCaskey there were many of these crystals at that place. The following notes are from a manuscript report by McCaskey:

> In northern Palawan, on the trail between Malampaya Sound and Taytay, I found highly siliceous rocks and quartzites similar to those of the Calamianes Islands. These rocks occur at Taytay also, and the small fort at this place, built in the eighteenth century as protection against Moro pirates, is upon a spit of land terminating in a knob of quartzite. From the base of this the living coral reef extends over most of the bay. The soils between Taytay and Malampaya Sound are similar to those of Busuanga and Culion.
>
> At the little village of Pancol, on Malampaya Sound, the stream pebbles and gravel are in part siliceous. South of Malampaya Sound rises the conspicuous Mount Kapoas, 1,020 meters (3,350 feet) high, with three nipples, with steep slopes, and with a waterfall on the north face. This mountain was reported by Commander W. T. Bate, of the British Navy, who made the survey of the sound in 1851, as being of granite. Gold has been reported

* Photographs of this region show two sets of wave cuttings, the upper of which indicates uplift; but the uplift was of much less magnitude than the great drowning of the coast attested to by the Malampaya embayment.

in the vicinity as occurring on Mount Kapoas, and some of the placer sands from the mountain were given me by the presidente of Taytay. From an examination of these, with a pocket glass, it would seem that the reported classification of Commander Bate is probably correct. The sand is largely of quartz, with feldspars that appear to be unstriated and with small grains of mica.

Little is known of the volcanoes of Palawan. My own itinerary did not take me to Dumaran Island, and I was able to learn nothing of the reported volcanoes of Alivansia and Talasiquin. Palawan is sometimes popularly said to be of volcanic origin, as are the Calamianes. Although I found volcanic rock in Palawan and although several of the peaks appear to be volcanic, no evidence is at hand to show that the origin of the island is volcanic. The evidence tends to the belief that the volcanic activity that may have been here is incidental rather than otherwise, whereas the Calamianes show no evidence whatever that they have ever known activity of this kind.

Across the bay from the town of Puerto Princesa at the base and on the southwest flanks of Mount Pulgar, I found everywhere a coarse-grained crystalline massive rock that upon microscopic examination appears to be a diorite. It seems to be identical with diorites of the Cordillera Central of Luzon, and, like them, is found in various stages from the fresh rock to the semidecomposed state. It is apparently composed of black hornblende, oligoclase and andesite, biotite mica, and a variable amount of quartz.

Neither volcanic nor sedimentary rocks were observed at this point. It would seem, from the testimony of all the stream beds crossed by me within a radius of 8 kilometers of Pulgar, that the crystalline rocks of the older series form the core of the range as they do in Luzon.

Upon the trail which leads from Separation Point or Island Bay, across the island to Alfonso XIII on the west coast, over a low country flanked by rounded hills of little elevation, I found quartz and jasper in the streams and soft sandstones and claystones in the hills. No evidence was seen in this region, or farther south, of geological conditions similar to those of northern Palawan; and I am inclined to think that Separation Point, which apparently marks a separation between topographic conditions north and south of this line of trail, also marks some degree of separation in a geologic sense.

I was unable to reach Alfonso XIII. The stream emptying into the sea at this place is reported to carry small amounts of placer gold. Stream tin is also said to be found in the vicinity. However, my sources of information were not wholly reliable, and I was unable to verify the reports.

At the small military camp and old Spanish blockhouse of Separation Point a red alluvial clay covers the coral rock to a depth of 1.2 to 2.4 meters as shown by excavations for foundations at this point.

On the beach at San Antonio Bay quartz and red jasper pebbles are found in great quantity. The finer beach sands, also, are but the alluvium from the mountain streams and are highly quartzose. In the hills southwest of San Antonio Bay I found a mountain stream cutting beds of a decomposed red slate and exposures of rhyolite, or quartz trachyte. The relation of these could not be observed from the time available and because the saprolite and vegetation so heavily covered the hills.

A very extensive development of coral growth is found off all the coasts of Palawan. The shoals are but imperfectly charted and most of them are extremely dangerous to navigation. For all the southern ports the services of a pilot seem necessary upon first voyage.

Coralline limestones are reported in Palawan. From my observation they are missing in the southern half and are probably found only along the north coasts. It seems not unlikely that they may be related, in time, to the Neocene limestones of Peñon de Coron and elsewhere. They are well-developed and apparently identical with those of Peñon de Coron, off the northwest coast, where I saw them in the Rugged Limestone Groups of the charts.

CUYO ISLANDS

On Cuyo Island there is andesite, as evidenced by a specimen collected during the Spanish régime. Of the group as a whole little is known geologically, in spite of the fact that the islands composing it are well known in other ways.

The following notes are from a manuscript report by McCaskey:

The little islands of Cuyo and Bisucay may be treated together, for I found them to be of identical origin and formation. Each consists essentially of a worn down volcanic cone of gentle slope, and the rock formations of each show doleritic and basaltic lava. These rocks are in places fresh, but are for the most part highly decomposed, furnishing by their erosion during the heavy rain a rich alluvium of red, and exceedingly fertile, soil. I could find no volcanic tuff on either island, and am inclined to think that the volcanoes once existing here are of great age, once much higher than now, and worn down to but remnants of their former extent. Both islands are surrounded by coral reefs from 0.5 to more than 1.5 kilometers wide. The lava upon Cuyo, east of the town and west of Mount Aguada, is in part vesicular.

A deposit of corundum was reported to exist upon Bisucay, and I made a search for this valuable mineral. It developed that the supposed corundum is magnetic and titanic iron sands, found with small quartz crystals upon the coral-sand beaches, and washed down in small quantities from the volcanic rocks above. On the east side of Bisucay the coral shoals are in part above the level of low tide, thus demonstrating at this point the uplift generally observed throughout the Archipelago.

CALAMIAN ISLANDS

Coron Island, according to Mr. Edward H. Taylor, is wholly of limestone. Of certain caves on that island he has supplied this interesting note:

There is a limestone cave on Coron Island, directly across from the town of Coron on Busuanga Island, inhabited at the present time by a very primitive people known as Tagbanuas. At the time of my visit there was no one at home, but there were remains of fire, pots, a hammock, etc., testifying to the recent occupation of the cavern. This cave is about 20 meters above the sea and close to shore. In addition to the articles

named there was a large kitchen midden consisting mainly of shells of edible mollusks and fragments of pottery. Just opposite this site are three small limestone islands. In one of these is a very small burial cave containing three cadavers, and one very recent coffin made of bamboo and nipa. According to report in Coron there are many Tagbanua cave dwellers on islands north of Palawan and on Culion.

The following notes are from a manuscript report by McCaskey:

Peñon de Coron.—Time was not afforded for a visit to Peñon de Coron, but I saw it from three sides, passed within a quarter of a mile of the north side, and have examined carefully several large pieces of rock of which the island is reported to be composed. There seems no doubt that Peñon de Coron is a massive mountain, 365 meters high, of semicrystalline limestone. This is probably the older Pliocene limestone found elsewhere in the Philippines, elevated in some cases, as in Cebu, over 600 meters above sea level.

Although the living coral reef is found in the water near Peñon de Coron, the rock of the island itself descends almost without modification at a steep incline into the sea and the water is relatively deep within a few hundred meters of the coast line.

One of the most important and interesting islands of the whole Archipelago is Culion, the site of the largest leper colony in the world. Tenison-Woods, an Englishman, reported "Paleozoic" schists and quartzite from Culion in 1886. In the Philippine group are many islands the geology of which is little known, for the reason that they have not been studied by mining engineers or geologists.

Of Culion McCaskey has this to say in his manuscript report:

Culion.—At the base of the rounded hill upon which the town of Culion is built the wave action of the sea has produced a continuous exposure of highly metamorphosed, twisted and contorted, and occasionally faulted, quartzites. The quartzite is light yellow, varying to pink; it is very hard and has every appearance of great age. At a point where a thickness of about 18 meters was observed, one hundred sixty thin but distinct laminæ were counted. A black, fused, pitchy mass was found in places in these strata. This has not been analyzed, but is apparently hematite with earthy impurity. The upper exposures of the hill were of the same quartzite with cubic jointing, and of argillite, and the soil, as might be expected, is thin and poor.

J. C. Tenison-Woods * is credited with the statement that Paleozoic schists are found at this point. I have not access to the article and am not informed as to the paleontologic data from which this conclusion is reached; but it would not be surprising to me should further work demonstrate that the assertion is well founded.

* Nature (1886).

Where the waves cut the bases of the hills, around the northwest portion of the island, frequent exposures similar to the above were observed from the deck of the steamer.

At the Palanca hacienda, in a broad open valley between low rounded hills in the extreme northwest part of the island, there is a small stream flowing from the junction of two others, and at tide level through mangrove swamps to the sea. Above the mangroves, and in the valley at an elevation of 2 to 3 meters above low tide, this stream cuts through quartzose breccia and conglomerate. A flat rounded stone of fine-grained schist was found in the rocky stream bed. Above the conglomerate and in the valley plain, I observed for several kilometers a sandy soil of grains similar to the quartzites, and in the dried water holes a hard, blue-white clay which is undoubtedly the alluvial wash from the argillite of the hills above. The few rock exposures observed here were of quartzite similar to that of Busuanga and of eastern Culion.

In passing around the west side of Culion great exposures, apparently of quartzite, were observed from the steamer, as before, not only at the bases of the Culion hills but also at the bases of the little islands in the channels. North, northwest, and northeast of Culion fringing reefs of living coral run from the shore line of the island out to the ship channels. *Madrepora* and *Maeandrina* were conspicuous among the corals.

There are precipitous slopes of well-rounded hills at the entrance to Halsey Harbor and along the west coast generally. The exposures all seem to be of reddish and yellowish quartzite and argillite.

The low well-rounded hills of the Cogonal Grande, wherever I examined them, are broken quartzite. These hills are from 400 to 1,000 feet high, and are covered with a thin clay-sand soil and, for the most part, with cogon grass, although occasionally with forest growth. The streams run over sandy and pebbly bottoms in part, and the broad plains show a blue-white clay in all the water holes. The soil does not seem fertile in comparison with the rich limestone and volcanic soils found elsewhere in the Islands.

Busuanga.—I landed on the south coast of Busuanga only, at the town of Coron. The exposures here, at an elevation of 6 to 12 meters and representing, from what observations I could make, the neighboring hills, were of a highly siliceous rock that seems to be identical with the quartzites I found in Culion and in northern Paragua. There seems to be no reason why Busuanga and Culion should not be considered as of a single geologic group.

APO ISLAND

The following notes on Apo Island are from a manuscript by McCaskey:

Our exploration of Apo definitively determined that this small island is of coral formation. The evidence is complete, and the island itself is formed entirely from the products of coral growth.

The general formation of Apo is very much that of a lagoonless atoll, or rather that of a very small atoll in which the lagoon has been replaced by sediment, blown or washed over the rim, and now become a mangrove swamp.

The island is elliptical with its longer axis east and west. The center is a low mangrove swamp about 1.5 meters above low tide, and the rim surrounding this is of coral sand and débris on the north, east, and south, from 2.5 to 3 meters above low water, and of coral limestone on the northeast, northwest, west, and southwest, from 3 to 5.5 meters high. The shelving coral-sand beaches run down in little terraces to the sea and to the living coral which extends as shoals to a deep passage separating Apo from Menor, a similar coral islet, and for a radius in general and with breaks, of 32 kilometers to the west, north, and east.

The coral sand shows minute fragments of white, blue, and red corals, and the specimens of living coral gathered on the reefs identified, as might be expected, in the sands, represent the great reef-building genera *Madrepora*, *Astraea*, *Maeandrina*, and *Porites;* also a red *Tubipora* and a beautiful blue and green coral, probably a *Porites*.

The limestone cliffs are of well-hardened, compacted rock and invariably heavily eroded by the sea, and dissolved by the rain water carrying very small quantities of carbonic acid gas, the result of these agencies being that the rock is undermined and penetrated by holes and caverns; it has a rough surface above terminating in knifelike pinnacles. Thus, the pure coralline limestone, where exposed, is being rapidly returned to the sea. In addition to the above a soft, yellow colite is found, formed of imperfectly compacted coral sand and minute shells.

According to the subsidence theory of Darwin, Apo and Menor are the last evidences of old volcanic cones that have subsided and have had built upon them the coral reef; the gradually contracting reefs are now represented by very small islets in the midst of the deep Mindoro Passage. There seems, however, no perfect security to the unqualified application of the theory here.

United States Coast and Geodetic Survey Chart No. 4714, of Mindoro and adjacent coasts, shows a sounding of 90 fathoms and no bottom in the narrow passage between Apo and the large reef of which Menor and the Cayos de Bajo are part; it further shows soundings of from 26 feet and a rock bottom to 445 fathoms and no bottom immediately surrounding the reef; and corresponding depths separating the Apo group from the small outlying shoals and reefs on the west, and still greater depths of sea separating these coral islets as a whole from Mindoro on the east and from the Calamianes Islands on the southwest. These apparently represent great subsidence of early mountain cones, therefore, and a break between the Calamian-Paragua [Palawan] group (in many respects closely allied to Borneo) and Mindoro.

SEMIRARA

Practically all that is known of this island is that it has coal, clearly the continuation of seams on the southern end of Mindoro.

MINDORO

Of this island somewhat more is known than of the rest of the group, though the data are far from complete.

Merrill ascended Mount Halcon with the late Lieut.-Col., then Maj., E. A. Mearns, in 1906, and brought back specimens of rock from the summit that I identified as andesite.

On the northern side of the island there are some metamorphics, schists, etc., in which are some auriferous veins, the continuation of those on Lubang Island. Placers derived from these have attracted attention for many decades; those on Binaby River are apparently the most alluring, but no one has made a success of mining there.

The interior of the island is largely unknown. As can easily be seen from the sea in passing boats, this part is high, rugged, and densely wooded.

On the south end of Mindoro, particularly near Bulalacao, deposits of coal of about the grade of East Batan coal have long been known, and in Spanish times attempts were made to work them. I visited these deposits in 1910, and was not favorably impressed by their commercial possibilities. They are of middle Tertiary age, like the coal throughout the Archipelago.

In 1913 Dalburg spent a short time on southern Mindoro, near the San Jose sugar estate, but his work was largely in the lowland alluvial country. He noted some Tertiary shales in the foothills and limestone cliffs, probably Malumbang (Pliocene), along the coast. He heard of alleged oil seeps in the interior, but did not have the opportunity of investigating them. This portion of Mindoro was long known as the "White Man's Grave," owing to the prevalence of malaria and other diseases. It is now the site of one of the largest sugar plantations in the Archipelago.

Recently (1921) Messrs. Moody and Kryshtafovich, while exploring in the southern part of Mindoro in the interests of an oil company, found several teeth of a species of shark, *Carcharodon arnoldi* Jordan, in a presumably Miocene marine conglomerate.

Mindoro is very interesting, zoölogically and ethnologically, and apparently has been separated from the rest of the Philippines for a long period. It has the distinction of being the home of the timarau (*Bubalus mindorensis* Heude). This animal is much like the water buffalo, or carabao, but is smaller, and its horns are shorter, straighter, and nearer together at the tips.

The indigenous people on this island are very different from the other Philippine ethnic groups, though they may be remotely related to some of them. They are known as Mañgyans * and

* Prof. H. O. Beyer points out that there are two distinct groups included in the Mañgyan.

speak a dialect used nowhere else in the Philippines. They are a very shy, primitive people.

LUBANG ISLANDS *

Geography and physiography.—Lubang Islands comprise a group of small islands lying northwest of Mindoro, about 130 kilometers southwest of Manila, and about 40 kilometers west of Cape Santiago, Batangas. The principal islands are Lubang, Golo, Ambil, and Cabra. There are two organized municipalities, with seats at Lubang on the north and at Agkawayan on the south part of Lubang Island. The islands were formerly part of Batangas Province, but at the present time they belong to Mindoro. They are sparsely inhabited. No steamers call regularly at these islands, and communication with the mainland is by means of sail boats. The waters surrounding the islands are safe for sail boats during April, May, and June, but the rest of the year they are subject to frequent storms.

The country in general is mountainous and of extreme relief. On the northern part of Lubang Island there is a narrow strip of coastal plain which is mostly cultivated for rice growing and partly planted with coconut trees. The middle and southern parts are rugged and much broken. Rice is grown on the hillsides and on the narrow plains near the numerous indentations along the coast. The mountains in the central part rise very abruptly and are covered with forest which, though not abundant, is sufficient to supply the needs of the inhabitants for construction purposes.

Golo Island is inhabited only on the northern and southernmost parts. Like Lubang, it offers very sharp contours. The hilltops are mostly covered with cogon grass with very little forest.

Ambil Island is made up of one solid mountain of considerable altitude with steeply inclined sides rising regularly. A small area of the summit is covered with forest; the rest is entirely barren or partly covered with cogon. A few settlements were noticed on the western coast.

General geology.—A trip was made only along the coast; hence the following statements are based on evidences found and observed along the shore:

* The section dealing with the Lubang Islands is contributed by Victoriano Elicaño.

Lubang Island is traversed east and west by a belt of granite intrusion exposed at the narrow isthmus of Looc, extending from coast to coast between Looc and Tabahin Bays and from the barrio of Looc to about 2 kilometers toward the southern end of the island. Micaceous schist flanks both south and north boundaries of the granite. Northward along the western coast the schist, alternating with gneiss, can be traced to Quebrada Point, and from here a formation of slate is observed, grading from schistose to compact clay slate, which is cut abruptly by a coralline formation around Diablo Point. An old fragment of unaltered sandstone has been picked up at the mouth of a stream between Quebrada and Diablo Points, but the original formation has not been identified on the coast.

From Diablo Point the coralline formation disappears under the coastal plain, but is again identified on the eastern coast near the barrio of Vigo, covering a mass of serpentine which is lost in the schist formation that appears again from Balikias Bay to the granite belt at Looc. Ambil Island was not visited, but the rocks observed from the boat along the northwestern coast are apparently similar to the serpentine found in Lubang Island.

As mentioned above, the granite is bordered on the south by schist, which is similar to that found on the north side. This schist can be traced across the Golo passage to the north and south parts of Golo Island. The central part of Golo is formed of serpentine, and it has been noted in some hills that the serpentine is capped with coralline formation.

From the data in hand it seems that the serpentine constitutes the basal formation over which the metamorphosed sedimentaries were laid during the period of submergence of the former. Probably contemporaneous with the formation of the coral beds, or preceding it, the intrusion of the granite metamorphosed the sediments into their schistose forms, and the subsequent elevation of the region brought up the coralline formation to the present state. The presence of schist in the southern portion of Golo Island cannot be accounted for by the Lubang granite although it may have some connection with a similar granite noted on the northern part of Maricaban Island. The lack of observations on the northern part of Mindoro and Ambil Islands makes this correlation only tentative.

Contact metamorphism has produced the quartz bodies of varying sizes that are found in the schist near the intrusive

granite. No quartz veins have been noted in the schist on the southern part of Golo.

Economic geology.—Farming and cattle raising are the most important industries of the people. The littoral deposits as well as the disintegrating schist furnish fairly rich soil for the agriculturists. The only mineral deposit of economic importance so far discovered is the quartzose sand and quartz gravels. In connection with the proposed establishment of a glass factory in the Philippines, these materials have been used in the experiments carried out by the Bureau of Science, and they have given very satisfactory results. The following analyses give their average composition:

TABLE 20.—*Average composition of Lubang sand and gravel.*

	Vein quartz.	Quartzose sand.
Loss on ignition	0 34	0.80
Silica	97 49	86 60
Ferric oxide		0.48
Alumina	1 58	8 12
Lime	Trace.	1 20
Magnesia	Trace.	0 22
Manganese oxides	Trace.	
Sodium and potassium oxides	0 50	
Undetermined		2 50

Local foundries have found the quartzose sand to be an excellent material for core making, thus giving it another commercial application.

The quartzose sand is the result of disintegration of the granite, and the accumulation is found on the shores bordering that rock. The best deposits are on the southern shore of Looc Bay and on Tabahin Bay on the western coast. Together, they may be more than 5 kilometers in length and about 0.5 kilometer in width, with a depth averaging over 1 meter. Between the high- and the low-water lines the sand is free from clay, due to the constant action of the waves. There are places where the sand grains are all quartz, but the bulk of the deposit is a good mixture of quartz, feldspar, and mica.

The quartz-gravel deposits are found principally along the coast bordering on the schist formation close to the intrusive granite. Great accumulations are found mostly in the inlets, although the hills are also covered with fragments of varying sizes.

The quartz has been assayed in the Bureau of Science and showed no trace of gold. People at Agkawayan, however, say

that about 1909 or 1910 some American prospectors staked claims around Pula Hill, but these were abandoned later. A few floats of honeycomb quartz were found on this hill, but upon assay they showed no value.

BATANES AND BABUYANES

Practically the only reliable geologic data on these seldom-visited islands is contained in one published paper on the physiography of the group, by Ferguson,* and in an unpublished preliminary general report by the same geologist. (264)

Ferguson has not had an opportunity to revise his report, but it covers the general geology better than the more specific paper on the physiography and it will be used here with slight alterations.

Since Ferguson's visit in 1907 there has been some desultory exploitation of the sulphur deposits on Camiguin, but just now even that activity has ceased.

Attention is particularly invited to Ferguson's discussion of the relationships with Formosa (or, rather, their lack) as they are especially pertinent in the larger discussion of Asiatic paleography.

The Batan Islands lie between latitude 20° 16′ and 21° 05′ north (21° 13′ if the "existence doubtful" Bashi Rocks are included) or approximately the latitude of the southern half of the Hawaiian Islands, and between longitude 121° 49′ and 122° 02′ east. Y'Ami, the most northern island, is about 270 kilometers from the nearest point of Luzon, Cape Engaño, 107 kilometers from the Japanese island of little Botel Tobago, and 160 kilometers from the southern point of Formosa. It is said that on a very clear day the Formosan mountains can be seen from the summit of Mount Iraya in Batan Island. Bashi Channel, with a minimum depth of 1,009 fathoms, separates the islands from Formosa and the Botel Tobagos; while on the south Balingtang Channel, with a depth of 95 fathoms without bottom, lies between them and the Babuyanes group. The Balingtang Islands, lone rocks rising perpendicularly from the sea, lie in the center of Balingtang Channel and form a connecting link between the Batanes and the Babuyanes.

The Batanes people form a separate race, speaking their own language, or languages, for that of Isbayat is different from that of the other inhabited islands. Scheerer † considers that the inhabitants of Batan and Sabtan are of Malay stock, while those of Isbayat are mixed Malayan and

* Mr. Ferguson resigned from the Philippine service in 1910 and has not revisited the Islands. He is now a member of the United States Geological Survey.

† Scheerer, Otto, Zur Ethnologie der Inselkette zwischen Luzon und Formosa, Mitteilungen der Deutschen Gesellschaft für Natur- und Volkskunde Ostasiens 11[1] Tokyo (1906).

Papuan. They are a kindly, intelligent, enterprising, and extremely industrious people.

The islands were discovered and charted by William Dampier in 1687. He named them the Bashi Islands and claimed them as British territory. They were visited in the same year and in 1724 by Dominican missionaries from the Babuyanes, but it was not until 1791 that the Spanish Government was established.

The islands may be roughly divided, geologically, into three groups, as follows: *a*, Sabtan and the southern part of Batan, consisting largely of volcanic agglomerate with occasional basic dikes, particularly in the southern portion of Sabtan; *b*, northern Batan and the chain of small islands to the north, of recent volcanic origin, the material being largely basalt and andesite with subsidiary agglomerate containing volcanic bombs; *c*, Ibujos, Desquey, and probably Isbayat, composed entirely of coral limestone.

Uplift is shown by the presence of marine terraces and coral limestone to a maximum elevation of 900 feet [about 275 meters] on Batan Island, and 700 feet [about 215 meters] on Sabtan. The topography of the agglomerate region, except where modified by marine terraces is in general extremely rugged and sharp, with steep ridges running in all directions and cut by deep cañons. The maximum elevation is 1,500 feet [about 450 meters] at Mount Matarem in Batan. Diagonally across Sabtan Island is a belt of rolling upland country, where the valleys are mature and open and the streams at grade, in general a mature topography. This plateau has an elevation of about 1,000 feet [300 meters] and is bounded by a sharp escarpment of agglomerate, irregular on the eastern side but forming a straight line of cliffs on the west. It may be considered to represent the pre-Miocene topography.*

The agglomerate formation contains occasional small areas of stratified sandstone and conglomerate, apparently of fluvatile origin. On the west coast of Sabtan marked westerly dips were noticed. Both the agglomerate and conglomerate are much fissured and faulted, the displacement being generally small.

The extinct volcano, Iraya, dominates the northern portion of Batan. * * * The entire northern part of Batan Island, that is, north from San Carlos, is covered with detrital wash from the mountain. This forms cliffs of conglomerate often as much as a hundred feet high, consisting of fine and coarse layers of volcanic pebbles and sand. There is often cross bedding showing stream deposition. Along the stream valleys this material has slowly crept down, giving a rough bedding parallel to the slope. In one or two places where road cuts have been made, the horizontal bedding is seen grading into the bedding parallel to the surface. From Santo Domingo northward to Diojo Point and along Sonson Bay there are high cliffs of coral limestone mixed with limestone conglomerate.

Of the other islands of recent volcanic origin there is little to be said. Innem is a solitary peak rising from the sea to a height of over 1,800 feet [550 meters]. On the chart it is noted as "volcanic" and is apparently an extinct volcano that has suffered considerably from marine erosion. Many

* This is hardly possible under the conditions of erosion existing in the Philippines. The topography is probably of much more recent origin.—W. D. S.

of the inhabitants report having seen steam coming from the summit, but I think this is very doubtful, the report probably originating from the small clouds which often rest on the summit. From the deck of the steamer I could see nothing that would indicate recent activity. Siayan and Mabudis seem to be composed of igneous rock with a small amount of limestone. Y'Ami Island on which I landed is, except for a few feet of coral near the shore, entirely of volcanic origin, consisting of an agglomerate composed largely of basalt bombs and several small flows of basalt. These flows seemed to be continued on Maysanga (North) Island, a small island to the south. I did not have time to reach the top of the island and so am unable to say whether there has been any recent action. I do not think it probable, however, and I regard this chain of small islands as simply erosion remnants of a much larger volcanic island.

Ibujos Island consists entirely of coral limestone rising over 200 feet [60 meters] in steep cliffs. These cliffs surround the island except on the eastern side, where the land rises gently from the fringe of sand dunes around the shore, in contrast to the 1,000-foot [300-meter] agglomerate cliffs of Sabtan Island only a mile away. The surface of Ibujos is gently rolling, but without streams or definite stream valleys. This is partly due to the solubility of the rock which allows the water to run off in underground channels, but is also in large part an effect of the lateness of the uplift which has not allowed time enough for the streams to form valleys. The soil seems to be volcanic ash rather than limestone, but I have not yet made a microscopic examination of it. Desquey, the little island west of Ibujos, seems to be the same, but it is entirely cliff bound.

Isbayat, the largest island of the group, is likewise entirely surrounded by cliffs, the only landings being steps cut in the rock in one place and a series of ladders in another. From the deck of the steamer the cliffs seemed to be exactly similar to the limestone cliff of Diojo Point, on the north of Batan Island, and I am told by people who have visited the island that from the top of the cliffs the land slopes downward toward the villages which are situated in small "sinks." This fact inclines me to believe that Isbayat is composed of limestone rather than of volcanic material. The island is said to be the most fertile of the group, but has a bad reputation for unhealthfulness, the inhabitants of the other islands suffering from fever whenever they go there.

The geologic history of the Batanes may be briefly summed up as follows:

A land mass of considerable extent formed by agglomerate, volcanic action following, as is shown by the dikes which cut the agglomerate formation.

This land, whatever its original form and size, was gradually degraded to a peneplain which probably extended over an area much greater than the present islands of Batan, Sabtan, Ibujos, Desquey, and Isbayat. Then began the uplift of Batan and Sabtan which has continued almost to the present time. These periods of uplift are marked by terraces for the more recent and by irregular outcrops of limestone for the earlier.

The relations of the two limestones, already determined [by W. D. Smith] to be Miocene, with the other rocks are not clear, but it seems certain that they are more likely to be contemporaneous with the formation of the agglomerate. They certainly form no part of the terrace series.

If contemporaneous, or nearly so, with the agglomerate, then the whole geological history of the islands must be post-Miocene.

Uplift has of course resulted in renewed cutting power of the streams, and the agglomerate area is dissected into a series of irregular ridges with steep cañons, especially in the southern part of Batan.

That the land is at present stationary or undergoing slight depression is shown by the high cliffs of loose material in the northern part of Batan. To maintain a cliff of such material the sea must be constantly cutting on the cliff, otherwise it would soon slough down until the angle of rest of the particles composing it is reached. If the land were rising at all a bench would soon be formed, which would protect the cliff from wave action and soon cause it to lose its form by weathering.

Vulcanism seems to have accompanied each stage of the geologic history. The dikes found cutting the agglomerate in the southern part of Sabtan probably acted as feeders to Miocene volcanoes. Possible remnants of old flows are found in the north of Sabtan, and the southeast and central parts of Batan. During and after the period of elevation volcanoes were active at Iraya, Innem, and probably on the northern islands. The later eruptions are characterized by basaltic lava, whereas the earlier ones were largely andesitic in character. All of the volcanoes of the Batanes are now extinct, and Iraya alone retains its symmetrical form.

After leaving the Batan Islands, I went to Camiguin, the most southern island of the Babuyanes group and remained there five weeks. On the way I was enabled to remain about two hours on Babuyan Claro, where there is a volcano which has been active as recently as 1860. There are two volcanoes on this island, one a beautifully symmetrical cinder cone, about 2,200 feet [670 meters] in height, and the other less symmetrical but showing two craters which contain steam vents. The smaller volcano contains, besides the fine ash that gives it its shape, a recent flow of scoriaceous basalt. The older flows of this volcano are also basaltic. There has been no serious eruption since 1860. The few people living on the island report, however, that steam explosions occurred on the smaller mountain ten years ago and on the larger four years ago. No ashes reached the village in any of these explosions, however. As it is only in the last thirty-five years that the island has been inhabited, the inhabitants knew nothing of the eruptions of 1860. Reports are numerous of a red glow being seen in the sky above the volcano, but I am not certain how much credence should be placed in them. The islands of Calayan, Dalupiri, and Fuga (Babuyan) I was not able to visit. Mr. McGregor, ornithologist of the Bureau of Science, who has visited Fuga and Calayan, tells me that limestone terraces are a marked feature of both, Fuga being entirely limestone, and Calayan, besides its limestone terraces, containing a columnar igneous rock.

Eastward from Camiguin are the Didicas Rocks where between 1856 and 1860 there was an eruption which built up a volcano to the height of about 700 feet [215 meters]. This volcano must have been composed of loose scoriaceous material, since scarcely anything now remains of it.

On Camiguin I was unable to do field work for about ten days on account of a lame foot, and for four days I was ill with malaria. The remainder of the time I was greatly handicapped by the thick brush (being

unable to hire any laborers or to get a bolo for myself) and by the loss of my barometer. I could therefore do little more than make a rough map of the shore line and some of the streams, on which I plotted the outcrops. * * *

The northern part of the island is mountainous and heavily wooded, but as far as could be seen none of the other mountains are recent volcanoes.

A peculiar feature of Camiguin and probably also of Babuyan Claro is the absolute lack of any evidence of elevation. The streams enter the sea at grade forming large marshy floodplains, on one of which is situated the barrio of Camiguin. On the plain back of the barrio I picked up a few limpet shells. These were near a house and so are of no value as evidence of elevation, as limpets are eaten by the natives. In any case this would not indicate an elevation of more than about 20 feet [about 6 meters].

STRUCTURAL GEOLOGY

Two problems in the structural geology of these two groups present themselves: the origin of the Batanes agglomerate, and the tectonic relations of the Batan Islands with the Babuyanes, and of these groups and northern Luzon to the south, and Formosa and Botel Tobago to the north. My first idea in regard to the agglomerate was that it was the result of the blowing off of the old cone of Mount Iraya, but as soon as I realized the amount of material in the agglomerate, at a moderate estimate one and three-quarters cubic miles of material above sea level, this was seen to be impossible. Besides this, later examination of the agglomerate showed that it is the oldest formation in the Islands, probably far older than Iraya Volcano.

North of the little barrio of Ithod on the southern end of Batan there is a wide amphitheatral basin drained by two parallel streams which cut steep cañons through an agglomerate ridge. In this basin the stream valleys were broad and gently sloping and the streams apparently at grade. Outcrops were found of an andesitic rock, faulted, and pyritized along the fault plane. The surrounding walls were all agglomerate. At first sight it seemed as if this basin represented the explosion crater from which the agglomerate had been erupted, and the andesite in its crater, a volcanic plug; but after seeing the Sabtan upland I concluded that it was useless to attempt to explain the origin of the agglomerate by means of existing physiographic forms.

The roughly circular outline of the Babuyanes group, together with the fact that agglomerate of the same geological age was found by W. D. Smith in Ilocos Norte, indicate that a vast explosion crater here may have been the origin of the agglomerate. But there are grave objections to this hyphothesis. In the first place, if there had been explosions here of sufficient magnitude to throw blocks 10 feet [3 meters] or more in diameter a distance of 60 miles [100 kilometers] to the north and smaller stones a similar distance to the southwest, it is curious that there should be no masses of agglomerate in the Babuyanes Islands themselves, and no contemporaneous "ash" deposits in the Batanes and Ilocos Norte. "The volcano of Antuco in Chili is said to send stones flying to a distance of 36 (?) miles; Cotopaxi is reported to have hurled a 200-ton block 9 miles; and the Japanese volcano, Asama, is said to have ejected many blocks of stone,

measuring from 40 to more than 100 feet in diameter."* Again, the circular form of the Babuyanes group seems on further study to be probably accidental, as Babuyan and Camiguin Islands, together with the Didicas Rocks, belong in the neovolcanic band to be discussed later and show no evidence of uplift, while Calayan, Dalupiri, and Fuga are at least in part islands of recent uplift. The best that can be said in accounting for the origin of the agglomerate is that in Miocene or pre-Miocene times there were tremendous outbursts of volcanic activity at centers north of Luzon, in a region already volcanic, as the pebbles of the agglomerate seem to be all of effusive material. These outbursts were of more than Krakatoan dimensions, and built up a land in the region of the southern Batanes of considerably greater area than at present, and also the agglomerate ridge which W. D. Smith discovered in Ilocos Norte. That these, at least as far as concerns the Batanes, are not the product of a single explosion is shown by the presence of sandstone and conglomerates, probably of fluviatile origin, intercalated in the agglomerate formation. It is perhaps a little far fetched to attempt such a correlation of the agglomerate in Ilocos Norte with that of the Batanes, over 200 kilometers distant, but the presence of two such distinctive formations of apparently the same age is certainly significant. It will be interesting to see whether an examination of the western part of Cagayan Province will reveal more of this agglomerate.

The difference in structure and topography between the neighboring islands of Sabtan and Ibujos is extremely striking, Sabtan having on its western side a straight line of agglomerate cliffs, reaching an altitude of over 1,200 feet [365 meters] and broken only by narrow cañons, with the fall line close to the sea, and Ibujos, composed entirely of limestone (age as yet undetermined), rising gradually on its eastern side toward the west. This striking difference of material and topography, together with the straight coast line of the western side of Sabtan, to say the least, strongly suggests a fault line between the two, with upthrow on the east. If we accept this fault on the evidence as given above and prolong it to the north and south we obtain some suggestive results. Extending the line northward in a direction north 6° 35′ east, brings Isbayat probably (similar to Ibujos) to the west of the line and Y'Ami, Mabudis, Innem, etc. (neovolcanic), on the eastern side. Following the same line to the southward there is a similar separation of the neovolcanic islands of the Babuyanes group, Balingtang Rocks (probably volcanic), Babuyan Claro, Camiguin, and Didicas Rocks all lying to the east of the line. This line further extended would meet Luzon at the mouth of Cagayan River. Here the straight northerly course of the Cagayan (a river which according to the best maps shows incised meanders due to uplift) is suggestive.

Koto, in his paper on the structure of the Malayan Archipelago, shows a neovolcanic belt, extending from Botel Tobago through the Batan Islands, the neovolcanic islands of the Babuyanes, and Cape Engaño and Cagua Volcano in northeastern Luzon. Thence the belt bends out to sea, reaching Luzon again in Camarines Sur. A glance at the map will show the close alignment of the recent volcanoes and neovolcanic islands of the northern Philippines along the 122d meridian. The longitudes are as follows:

* Geikie, Text book of Geology 1: 292.

Y'Ami, 121° 58′; Innem, 121° 57′; Mount Iraya, 122° 01′; Balingtang Rocks, 122° 08′; Babuyan Claro, 121° 56′; Camiguin Volcano, 121° 52′; Didicas Volcano, 122° 09′; Cagua Volcano, 122° 04′. This volcanic chain extends from latitude 18° 13′ north or, if the "existence doubtful" Bashi Rocks are included, to latitude 21° 13′ north. The Sierra Madre is practically unknown geologically, being classed with the "older massives" by Becker on the strength of two specimens collected by Semper, one of peridotite and one of norite from the western side of the range in about latitude 17° north. Until further exploration of this range is made, the swinging out to sea of Koto's neovolcanic belt is probably the most reasonable hypothesis; but I wish to make the suggestion that, having carried rather an inferential fault border of a neovolcanic series as far as the mouth of Cagayan River, it is not beyond the bounds of possibility that the Cagayan Valley trough may be the continuation of the same fault boundary and that extinct volcanoes of comparatively recent date may be found among the mountains of the Sierra Madre. In this case the neovolcanic belt might be prolonged through the Sierra Madre and through the isthmus of Manila Bay to include Taal Volcano and thence to the southeast to include Isarog and Mayon Volcanoes as in Koto's map. A bit of additional evidence in regard to the connection of the northern islands with Cagayan Province is the following statement taken from the Census Report of 1903: "The earthquakes recorded in the Batanes Islands during the last few years show that these islands form a seismic region with the northeast of Luzon rather than with the northwest."

Correlation with the Japanese islands of Formosa and Botel Tobago is even more doubtful. Similar fossils of Miocene age are found in the Riu Kiu Islands to the north of Formosa. The Botel Tobago Islands (Koto Islands on Koto's map) are mapped by Koto as neovolcanic, his neovolcanic belt swinging to the west to include them. The outlines of this belt are inaccurate, however, in regard to the Batan Islands as they include all the islands, both volcanic and nonvolcanic. The true volcanic belt enters the Bashi Channel at about longitude 122° east, which would necessitate a very sharp westward curve to include Botel Tobago Island. To my mind the enormous depth of Bashi Channel, the shallowest sounding given being 1,009 fathoms, excludes the probability of any tectonic connection between the Batanes and the Japanese islands. Mr. Edmonds, supervising teacher of the Batanes, tells me that of the earthquakes felt in the islands during his two years' residence there, few were noted in Formosa, while the majority were felt in Luzon.

The meager soundings in the region of the Bashi Channel give the impression that it trends in a northeasterly direction. If so, it may represent a geosyncline or trough parallel to the tectonic lines shown by von Richthofen along the southeast coasts of China and Cochin-China and to the northwest coasts of Borneo and Palawan. This deep channel prolonged would enter the 4,000-meter deep off the northwest coast of Luzon and follow the 2,000-meter deep to the southwest of the Riu Kiu Islands, hence by inference making the Philippines and Japan (including Formosa) separate geologic provinces. On the other hand the volcanic island of Botel Tobago, longitude 121° 30′, and the great Taito furrow * running north 20°

* Hobbs, Tectonic Geography of Eastern Asia, Amer. Geo. 24.

east from the southern point of the island, together with the Taito range just to the east of it, may be more than mere coincidences. It is conceivable that the transverse Bashi trough may be of more recent date than the Batanes system and may have offset the Taito furrow and neovolcanic belt some distance to the eastward.

ECONOMIC GEOLOGY

Metallic minerals.—Dampier in describing the Bashi Islands says: "Both sexes wear Earrings made of a yellow Metal (they dig out of their mountains) having the weight and colour of true Gold but something paler; Whether it were such in effect or no, I am not able to say; it looks of fine colour at first but afterwards fades; which makes us suspect it, therefore our people did not purchase much of it. We observed the natives to besmear it with red earth, and then, putting it into a quick Fire till it was red hot, brought it to its former colour again." This is about as definite information as I could obtain on the occurrence of gold in the Batanes. The Dominican Friars told me that formerly all the ornaments in the churches were of gold from the Batanes, but these had all been carried away by the Katipunan army. Many of the women wore heavy gold earrings and bracelets, often of excellent workmanship. These I was told were all of Batan gold. The gold was light greenish yellow, answering perfectly to Dampier's description.

It is also an interesting fact that they use the same method of baking in red clay to put the desired tarnish on it. All of these ornaments were family heirlooms and as far as I could gather no gold has been taken out of the streams for the last seventy years and gold-washing has become a lost art.

There is a story that about fifty years ago, some shipwrecked English sailors dug a "very deep hole" in the stream bed near San Vicente (Batan) and got "a little gold." Possibly with more modern methods the streams might be reworked with some hope of success but it seems rather doubtful, and the inaccessibility of the islands would hinder work on a small scale. An iron-stained vein outcrop near San Carlos and a pyritized fault zone north of Itbot were sampled, but I have not had assays made.

A small vein of copper silicate was found in one of the later lava flows. It was not over an inch wide and was in an almost inaccessible portion of a sea cliff.

Nonmetallic minerals.—The soil of Batan and Sabtan is rich and fertile, being for the most part the decomposition product of volcanic material. The amount of flat valley land is so small, however, that steep hillsides are cultivated, and cutting away the trees on the ridges has led to the formation of large cracks near the tops of the hills showing where the soil, unsupported by tree roots, has slid toward the sea. In course of time, if there is no reforesting or hedging of the fields, much valuable land will be lost. Near Santo Domingo, where hedges surround the fields, this sloughing down was not noticeable.

On the beaches along the north coast I noticed a considerable amount of pumice. This might be collected and shipped to Manila.

Camiguin Island.—The principal feature of the economic geology of Camiguin is its solfatara on the west flank of the mountain about a mile from the sea. * * *

Besides the sulphur, there is a cave near the hot spring mentioned before where there is a considerable coating of native alum (kalinite).

* * *

On the eastern coast of the island, which I was unable to visit, there is a deposit of excellent whetstone. It forms one of the many points of the island and was described to me as "a whole mountain of the stone." Though I have not examined it microscopically or had an analysis made, I should consider it to be in the nature of siliceous precipitate, probably from some former hot spring.

SEISMOLOGY *

In the light of investigations of the last two decades, stimulated by the tremendous cataclysms of Messina and San Francisco, entirely new principles have been introduced into the study of seismic disturbances of the crust of the earth, and the old centrum theory of Mallet is now generally discredited.

Beyond a doubt, many seismic disturbances are due to volcanism; on the other hand, many are due to other causes. Many of the worst disasters we have experienced have had nothing to do with volcanoes; that volcanoes are near by is only a coincidence, or may be explained by the fact that the place where great disturbances in the earth's crust take place is naturally a zone of weakness, where molten material would be expected to seek an outlet. At the time of the Messina earthquakes Mount Etna, which can be seen from Messina, was comparatively quiet. The great disturbances at Messina, as is generally known, were due to an adjustment along the line of a great fault in the earth's crust, which is marked by the Straits of Messina.

The work of the Italian geological survey has demonstrated that these disturbances are propagated along very definite lines. So thoroughly did the Italian geologists do their work that, by superimposing upon a geologic and topographic map of Calabria Province another map showing the location of cities and all the works of man, with all historical data regarding earthquakes, one can see at once that certain points are more subject to earthquakes than are others; that points removed from these lines have suffered less or not at all; and that the greatest disasters occurred at intersections of these lines. These lines, which follow more or less definite systems, proved to be the projections of various earth lineaments, such as fault lines, joint lines, formation contact lines, and axes of mountain ranges.

The great California earthquake of April, 1906, is a striking example of this. This earthquake was due to a dislocation along the well-known San Andreas rift and, although the waves

* The chapter on Seismology was written in collaboration with Miguel Saderra Masó, S. J., assistant director of the Philippine Weather Bureau.

from this disturbance were propagated to varying distances on both sides, the greatest disturbance occurred along the line of this fault.

When one can indicate a point on a map and say definitely that here the crust of the earth is unstable, seismic geology is shown to be of very great practical interest to humanity in general and to engineers in particular; especially is this the case in geologically young parts of the world, like the Philippine Islands, where mountain building is in progress and where the evidences of recent vertical movement of various portions of the island mass actually can be measured.

Concrete examples of what these disturbances mean are to be had in the earthquakes of Messina and of San Francisco, and the eruption of Taal Volcano, Luzon.* The people of Messina had been warned repeatedly; but commercial interests were so great that they took no heed of their danger and, consequently, millions of pesos' worth of property, as well as thousands of lives, were lost in that disaster. The same is true of San Francisco. The reported property loss at the time of that catastrophe was 980,000,000 pesos.

The disturbances in the region of Taal were primarily due to the volcano; but Taal Volcano is located along a line of crustal weakness and at that time a very appreciable displacement occurred along one or more lines passing through Taal Volcano. One of these lines extended from the volcano to the coast through the town of Lemery, and the other from Taal Volcano to the barrio of Sinisian, making with the sea a triangular area of several square kilometers. The whole block dropped a meter or more, so that the sea washed inland for a distance of a kilometer over the main highway along this coast. The road between Lemery and Sinisian had to be reconstructed. The damage to buildings in the town of Lemery was considerable. Fortunately, no very large structures were located along these lines; had there been any, the property loss would have been much greater.

It is believed that most of the seismic disturbances in the Philippines should be attributed, not to volcanoes, but to displacements along the major structural lines of the Archipelago, of which faults are the chief. In view of the catastrophe of Taal Volcano and of eruptions at other points, like Camiguin

* For a still more striking example we have, of course, the recent earthquake disaster in Japan which had been predicted by Doctor Omori, the great seismologist of that country.

and Mayon, the layman is apt to have his perspective altered, and he is naturally prone to attribute certain phenomena to what he believes are causes but which are, instead, results of factors not yet ascertained. It should be borne in mind that volcanoes are merely incidents in the growth of the Archipelago. Both volcanoes and earthquakes may be traced to the existence of lines of weakness and crustal displacements. Many earthquakes are due entirely to volcanic phenomena; but it can be proved that the major earthquakes, and the majority of earthquakes in the Philippine Archipelago, are not due to volcanism.

We may not in our lifetime see a recurrence of such disasters, either at Messina or at San Francisco; but the time will surely come when there will be further displacement along these great earth rifts.* It is true that there probably never will be as great disasters in the Philippines, due to the fact that most Filipinos live in basketlike houses, which are the very safest at the time of an earthquake; but large engineering works have been constructed, others are being planned, and large public buildings are continually being erected. Hence it is of vital importance thoroughly to investigate this question in the light of all the data we possess.

Until 1863 nothing was written on Philippine earthquakes. Even at the present time there exist but few papers based on modern seismologic principles, and all of these have been written during the last ten years.

The principal studies on this subject in this part of the world in the past have been made by the Jesuit Fathers, founders and directors of the old Manila Observatory, who now have charge of the Philippine Weather Bureau with its seismologic stations. Various studies and a few memoirs have also been contributed by members of the Spanish corps of military engineers; by Centeno(126, 127) and by Abella,(3, 6, 13) engineers of mines; and by Becker,(50) the first American geologist to make any investigations in the Islands. Koto,(360) the Japanese geologist, and Montessus de Ballore,(41) the great French student of seismology, have also made contributions to the subject, though neither has ever visited the Archipelago.

As a prerequisite to an understanding of the following discussion the reader is referred to the chapters on Physiography

* The last great earthquake in the Tokyo region, where disturbances have occurred repeatedly in the past, shows what we may expect at almost any time.

and Geology, where a review of the salient points in the framework and materials in the Philippine geologic edifice will be found.

TYPES OF SEISMIC DISTURBANCES

Modern seismology reduces earthquake shocks to three types; namely, volcanic, tectonic, and rockfall. Many instances of these three types are to be found in the seismologic records of the Philippine Weather Bureau, and some of the most characteristic shocks will be briefly mentioned.

To the volcanic type belong all the earthquakes that are intimately connected with volcanic eruptions caused by explosions or sudden outburst of steam. These volcanic earthquakes, contrary to popular belief and to the ideas generally held for many centuries by scientists, are in reality of but slight importance and occur only in certain restricted districts.

The last eruption of Taal Volcano, January 27 to February 7, 1911, offered a very typical series of such earthquakes. On the night of January 27, severe earthquakes occurred on Luzon and in adjacent regions, while at the same time, or very shortly afterward, it was noticed that the principal crater of the volcano increased in volcanic activity. This activity as well as the frequency and intensity of the shocks continued to increase during January 28 and 29, until at approximately 2.26 on the morning of the 30th there took place the greatest and most-destructive eruption recorded in the history of the volcano. After this paroxysm of eruptive activity the volcano soon returned to its normal state, although the earthquakes continued to be very frequent during the three following days, January 31 and February 1 and 2, thus indicating that there was still an accumulation of energy in the interior of the volcano. During the eruptive period, namely, January 27 to February 7, nine hundred ninety-five shocks were recorded in the Manila Observatory, all of them between I and V of the Rossi-Forel scale. Some of the principal shocks were perceptible at a distance of from 120 to 200 kilometers. The meizoseismic area of the earthquakes was a prolonged zone which included not only the volcano itself, but also the south-southwestern part of Laguna de Bay and the bordering territory as far as the sea, some 20 kilometers away.

The decrease of perceptible intensity of the seismic action outside the epicentral area was, according to many comparisons made on the spot, 1° of the Rossi-Forel scale for every 15 kilo-

meters. The same result was also deduced from the fact that the maximum intensities of several of the earthquakes as felt in Manila, 63 kilometers distant, were from IV to V of the scale, while in the epicenter, judging from the effects in the ground and on buildings, they were from VIII to IX. These earthquakes were also felt at Taihoku, Formosa, some thousand kilometers away.

The reports of previous eruptions of Taal also make mention of numerous earthquakes, which no doubt possessed the same characteristics as those that occurred in 1911. A curious fact is noted in these reports; namely, that, while in the recent eruption the meizoseismic area extended 20 kilometers to the south-southwest, in the previous eruptions it extended to the north-northeast for about 30 kilometers, as far as Laguna de Bay. From this it is easy to recognize the direction of the rift on which the volcano originated.

In 1871 a series of volcanic earthquakes occurred on Camiguin, a volcanic island north of Mindanao. These earthquakes culminated in the opening of a small crater whose activity lasted four or five years. They were first felt in February, and increased in intensity and frequency until the morning of April 30, when the volcano exploded and the earthquakes suddenly ceased. The greater number of these shocks was perceptible on that island only, although many were strongly felt on the neighboring coasts of northern Mindanao and southern Bohol; only four or five, the intensity of which in the epicenter was between VII and X, were noticed at a distance of 250 kilometers.

To the volcanic type may also be referred the series of shocks felt sometimes in volcanic regions; as, for instance, around the old Isarog Volcano. The new theories of Hörnes, Branca, and Rothpletz seem to apply perfectly to such succession of shocks, which must be called cryptovolcanic or intervolcanic, and are caused by the push and expansion of liquid magma through deep, old channels but without sufficient force to make its way to the surface. The frequency of dikes in the earth's crust gives evidence that such pushes and expansions are common geologic phenomena.

The rockfall type embraces the earthquakes of small extent which, having their focus, or seat of origin, at a slight depth, are brought about by the fall of rock in caves and underground passages, and in certain cases by the settling of superficial rock masses displaced by tectonic seismic motion. It appears that

this is the predominant type of shocks felt in several nonvolcanic regions of the Philippines; earthquakes of this type are very often extremely difficult to recognize, on account of the distance between the seismic stations and the large extent of the uninhabited mountainous and forest districts in which they occur, so that often it is impossible to delimit the area where they are perceptible. The earthquakes of 1881 in Nueva Vizcaya are unimportant examples of this class. From January to October of that year there was a continuous series of earthquakes, the maximum of intensity and frequency occurring in September. To get an idea of this seismic period, the well-known catalogue of the missionary Xavert should be consulted. This catalogue covers sixty-three days between January and October, and contains the record of one hundred ninety-six earthquakes, with the hour at which they occurred. Phrases such as "almost continuous," "many more," "the whole day," "the whole night" appear twenty-five times in the list, thus indicating that the smaller earthquakes were not included.

Abella, who examined the effects of these earthquakes in the field, found that the meizoseismic area was of very small extent, and that its center coincided with the town of Bambang. The great majority of the shocks were only perceptible within an area of 60 kilometers, so that only five of intensity VII to IX exerted any influence beyond the province. Many of the data supplied by Abella fully confirm his statement, which is further strengthened by an examination of the records of the hourly observations, made in the Manila Observatory, with the Bertelli microseismoscope, or tromometer.

With the catalogue of Xavert before us, these observations have been examined again, and we have been unable to find any movement which could coincide with the Nueva Vizcaya earthquakes, other than the ones corresponding to the larger shocks mentioned above and three or four other, doubtful ones. The experience of seventeen years shows us that this tromometer, still in use at the observatory, indicates perfectly all earthquakes of any great extent, and of intensity III or greater, whose epicenter lies within a radius of 200 kilometers from Manila.

Abella deduced from these facts that the seat of origin of the earthquakes must be very superficial and of small extent; hence the conclusion, that there was little likelihood of any greater ones happening in the future, was fully verified. Such

earthquakes could not in any way be classed as tectonic, and hence Abella attributed them to volcanic influences, suggesting that the subterranean forces, which at that time had given greater activity to Mayon Volcano, might possibly have extended toward the northwest and affected Nueva Vizcaya Province, some 400 kilometers from Mayon. After the examination of Abella's report, it seems evident that the earthquakes of Nueva Vizcaya belong either to the rockfall or to the tectonic type; this opinion is strengthened by a consideration of the topography of the province. The whole province is an elevated mountainous region of the nature of a plateau, separated from the plains of Luzon to the south by a line of steep cliffs, and bounded on the west by a series of peaks whose precipitous western slopes rise abruptly from the deep cañon of Agno River.

Besides the earthquakes of Nueva Vizcaya, many of the series of shocks that take place in Benguet Subprovince seem to be of the same character.* They commonly shake, with preference apparently, the southern and higher portion of the province and its western slope belonging to La Union Province. Subsidences and landslides are every-day occurrences, not only in Benguet but also over a great portion of the Mountain Province where coraliferous limestone formations predominate. These provinces present remarkable exemplars of the so-called Karst type, especially on their western side. Shocks of the same class occur in other parts of the Archipelago; for instance, in southeastern Panay.

In the Philippines, as in all other seismic regions, most earthquakes originate along determined lines which constitute special features of the topography of the Archipelago, and which are usually surface expressions of faults, joints, and other geologic structures.

The region that has suffered most from violent earthquakes during the past fifty years is without doubt eastern Mindanao, particularly Agusan Valley. There are no seismic data of this region from a period more remote than 1889, probably because of the undeveloped state of that part of the Archipelago and the consequent lack of communication with the outside world. The great deep-sea trough, the Philippine deep, along the east coast of the island, indicates that it must have been the seat of many

* I do not fully agree with Abella and Saderra Masó in this conclusion.—W. D. S.

earthquakes since it began to form. In fact, to-day a seismograph at Butuan shows that, of a monthly average of ninety disturbances recorded, at least 50 per cent originate in this deep.

The southern coasts of Cotabato district are frequently affected by earthquakes originating in Celebes Sea. There seems to exist a region or structural line of great weakness extending eastward between Mindanao and the Archipelagoes of Sangi and Talaut. Some of the strongest earthquakes gave origin quite recently to great tide waves, or tsunamis. A botanist who remained three years and four months in the Sarangani Islands, situated in that line, reported a yearly average of forty perceptible shocks, a number which can only be equaled in the Agusan region.

In Mindanao there exist the following seismic regions: Davao Gulf and Cotabato district, between Apo Volcano and Illana Bay; the coast along Illana Bay and Lanao district; and the extreme western part of the island near Zamboanga. Basilan and the Sulu Archipelago are also in a region of great seismicity, although the epicenters seem to lie in the neighboring seas. Dapitan district in the northwest is affected by a submarine epicenter situated between Dapitan and southern Negros. All the central part of northern Mindanao comprised within Misamis district appears to be a region of much greater stability; but the neighboring island, Camiguin, has suffered much at different times from volcanic earthquakes.

The Visayan Islands include three regions of great seismicity; namely, Samar, Leyte, and Panay. Samar is mainly affected by fault movements in the Philippine deep running close to its eastern coast, so it is as unstable as eastern Mindanao. Its principal epicenter seems to lie near the northeast coast. In Leyte two volcanic centers are prominent, one on the southeast end and the other in the north. A rockfall epicenter lies to the west between the coast and Camotes Islands. Western Visayas, Panay, and western Negros are under the action of an epicenter located in the strait separating them, which extends southwestward into Sulu Sea. A very remarkable and active center of the rockfall type exists within Panay in the southern portion of Iloilo Province; shocks very limited in area, but of sufficient force to cause damage, are not infrequent.

Cebu and Bohol, and perhaps also Oriental Negros, may be considered as comparatively stable. However, Oriental Negros

very probably has been the scene of many volcanic earthquakes, though the data we possess are deficient. Volcanic formations more recent than the Pliocene do not occur in Cebu.

In southeastern Luzon, comprising the two Camarines, Albay, Sorsogon, and also Masbate, three well-defined tectonic epicenters can be located. The first is located along the Camarines depression; the second in the Pacific, northeast of San Bernardino Strait; and the third in the neighborhood of Masbate. Mayon, Isarog, and Bulusan Volcanoes represent minor volcanic centers.

The southern part of Luzon constitutes the second seismic region of great importance in the Archipelago. Four epicenters may be distinguished in it; namely, one in the east near the coast, which appears to stretch from the north of Lamon Bay to the south in the sea between Mindoro and Marinduque; the second between Mindoro and Luzon; the third in the China Sea, along the coast of Cavite and Zambales; and the fourth, which may be called the Manila epicenter, is situated in the eastern cordillera and its spurs, between Laguna de Bay and Baler Gulf. The volcanic epicenters of Taal and other volcanoes are not considered as having any connection with these.

Northern Luzon, northward from parallel 16°, incloses at least three extensive seismic regions. That of Pangasinan, whose long axis apparently crosses the island in an approximately east and west direction, from Baler Bay to Lingayen Gulf, following the edge of the central plain, may be a great fault line. The rockfall epicenters in Nueva Vizcaya and Benguet may be referred to this central seismic region. Various epicenters located in both Ilocos Norte and Ilocos Sur Provinces, either within the coastal ranges or close by in the China Sea, form a second seismic province. The third comprises the northern portion of the Cordillera Central and probably extends to the Babuyanes. Along the extensive Cagayan Valley, and within its confines, there exists one of the most important seismotectonic lines of the Archipelago, but since 1645 it has not given rise to any very great earthquake. However, frequent shocks of limited extent and intensity occur within this region, those originating in the north being probably volcanic, while those in the south are due to epicenters whose activity seems to be on the decline.

In the extreme northern part of the Archipelago, outside the limits of Luzon, can be located at least two epicenters close to meridian 122° east. One seems to extend from the volcanic

island of Camiguin southward to the northeast coast of Luzon; the other lies in the neighborhood of the Batanes. They seem to be of volcanic, or they may be of rockfall character; that of Batanes gives rise to very violent and destructive shocks of limited area, while the other has been harmless for centuries.

Therefore, none of the provinces of Luzon escapes from the effects of earthquakes. Some of them, as Isabela, Cavite, Tarlac, and Pampanga, have no known epicenter within their boundaries, but still are affected by shocks originating not far away.

SEISMOTECTONIC LINES

The map (fig. 16) gives the location of the principal seismic areas of the Islands, the principal epicenters in these areas (stars), and the general direction of certain principal mountain chains. Each figure includes one or more epicenters, and shows the general shape and extent of the meizoseismic areas corresponding to the greatest earthquakes that have occurred within the region limited by them. The earthquakes originating near the regions indicated by figs. 3, 5, 7, 8, 9, 10 and 20 have been too many to be specified. Twenty-five areas are recorded; two of these, 14 and 16, are undoubtedly due in large part to rockfall and volcanic activity, the other twenty-three we believe to be due to tectonic causes. This is probably quite contrary to the general belief regarding earthquakes in the Philippines.

Following the methods of other students of seismology, we have connected the various epicenters shown on the map by lines and have also added a few more lines where no epicenters are indicated. There is a remarkable coincidence between these lines and the principal lineaments in the Philippines. The reader should remember that these lines are not to be considered as fixed and certain, but merely as having a suggestive value in our interpretation of field and laboratory facts. The various lines are denoted *a–a*, *b–b*, etc., on fig. 16, for easy reference.

Line *a–a*, which is drawn through many epicenters, passes through the northwest corner of Ilocos Norte Province, follows approximately the coast west of Vigan, and cuts across the northwest portion of Pangasinan Peninsula. It is very probable that this line marks a fault line which lies at the inner edge of the coastal plain at the contact between the recent sediments and the older rocks. As pointed out by Dickerson, the

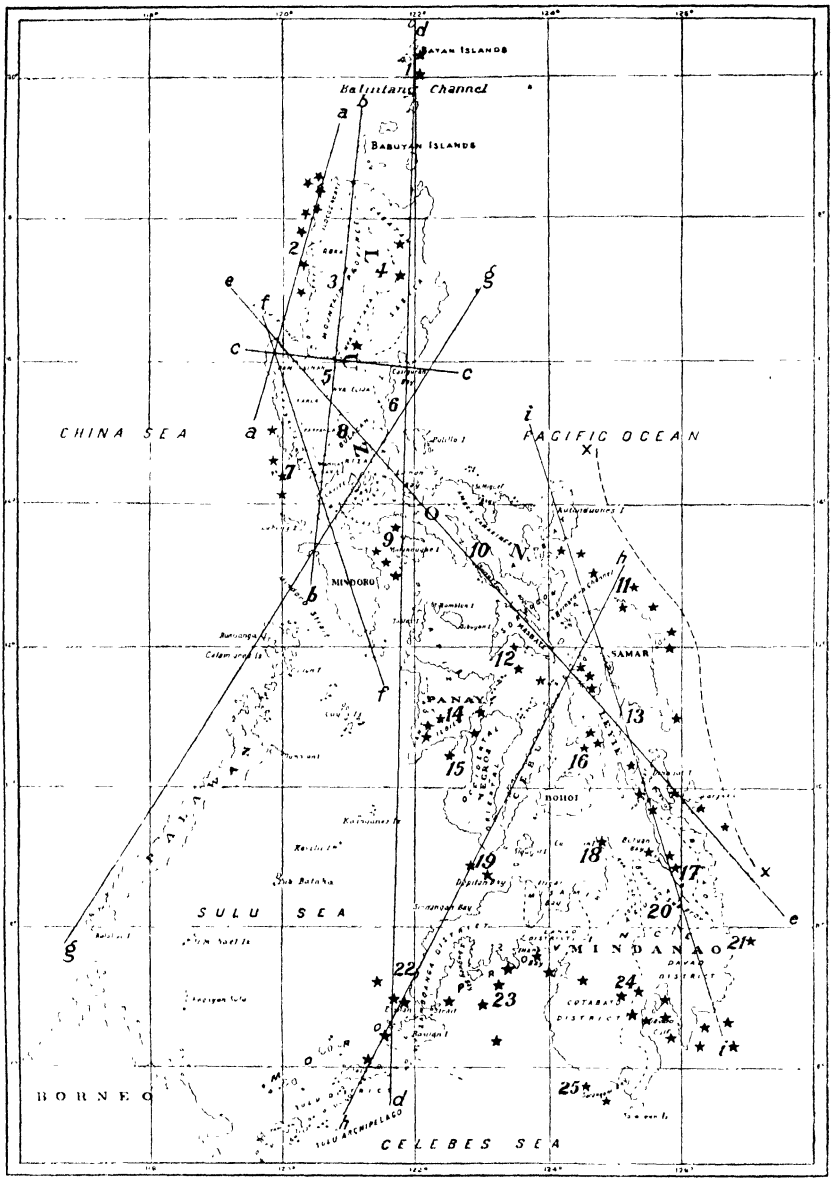


FIG. 16. Earthquake map of the Philippine Islands. Figures indicate seismic regions; stars, approximate epicenters; straight lines, main structural lines of the Archipelago.

hydrography indicates the probability of another parallel submarine fault farther west.

Raised beaches and raised coral reefs are prominent along this coast, making it plain that elevation has taken place near

this line in recent times. Whether or not this elevation has been accompanied by differential movement, we are unable to say. There is no evidence of recent volcanic activity in any part of the region, but granites, schists, and some very old andesites are present to the eastward of the coastal plain.

Line *b–b* connects epicenters of northern and southern Luzon; cuts through Dalupiri, the westernmost of the Babuyanes; then very closely follows the central cordillera southward through Agno Valley, thence to the eastward of the Zambales Range, and on through Mindoro, where it cuts the latter west of the great volcanic stock of which Mount Halcon is the principal peak. Dalupiri is mostly coral. The Cordillera Central in Luzon has a core of plutonic rock, chiefly diorite, flanked by Tertiary sediments which have been arched upward, and in various points along the crest of this arch extrusive rocks can be found in abundance. No volcanic activity now manifests itself in that region, but it is a region of hot and of salt springs. It is a line along which there has been considerable extrusion of igneous rocks, but there is no evidence of such extrusion now; therefore, seismic disturbances that take place along this line at the present time are due to displacement along a line, or perhaps many lines, of weakness (faults) rather than to any volcanic activity. It is significant that all of these points where either past or present volcanic activity is manifested are found to lie along more or less definite and, in many cases, straight lines.

Line *c–c* is the next prominent line; it runs at right angles to the *b–b* line, and lies either on, or very close to, four epicenters. At the upper end of the central plain of Luzon the mountains rise rather abruptly, and present a front which has a general east and west direction. It is possible that this line follows a fault line where the central plain represents the downthrow side. That area has not been studied in detail, but the topography is very suggestive of faulting. In a more arid region one would expect to find definite escarpments facing toward the south, but in a region of high rainfall like the Philippine Islands these escarpments naturally would very soon be obliterated, so that their existence can only be inferred.

Line *d–d* is a very prominent line which extends along the Archipelago close to the 122d meridian. It connects the epicenters of the Batanes, Cagayan Valley, Casiguran Bay, east of southern Luzon and Mindoro, and west of Mindanao. The northernmost part of the line, outside of Luzon, follows very closely the Batanes and Babuyanes volcanic chain, studied by

Ferguson,* and represented by the cones Y'Ami, Mabudis, Innem, Iraya, Balintang Rocks, Babuyan Claro, Camiguin, and Didicas. Within Luzon it passes not far west of Cagua Volcano, southward along the structural (synclinal with faulting) Cagayan Valley, following the trend of the eastern cordillera until this turns toward the southwest or, rather, where it seems to be interrupted by the gap forming Casiguran and Baler Bays. From the latter bay it follows the eastern coast of Luzon and passes to Mindanao Sea through or close to the volcanic region of Tayabas Province. A prominent north and south fault scarp east of Laguna de Bay coincides also with this line. Farther south it passes fairly close to Tablas, which is oriented in this direction; thence to the west coast of Panay, where some more faulting is suggested by the submarine topography; ending finally between Basilan and Jolo, where it intersects the *h–h* (Cebu) line. The general topographic features close to this line suggest that it is a very characteristic tectonic or structural line, though definite geologic data throughout its length are wanting to complete the evidence.

Line *e–e* passes through many epicenters. It lies just west of the epicenter near Bayombong, Nueva Vizcaya, passes through some epicenters near the east coast of Luzon and Lamon Bay and at the southeast corner of Leyte, and connects with the epicenters located around the northern point of Surigao Peninsula. This line is seen to conform to the central cordillera of Leyte, to the cordillera of Masbate, and parallel to faulting in Bondoc Peninsula. Farther northwest this line, prolonged, would pass through or very close to Mount Arayat. To the southeast it is determined by the faulting Ferguson observed some years ago along the west side of Ticao. Still farther south the Diuata Mountains in Surigao Province fall into line with this prominent tectonic lineament of the Archipelago.

Line *f–f* passes through Mindoro, thence along the western coast of Cavite, follows the western border of the central plain, across Pangasinan Province, and finally along the axis of the coastal ranges of La Union Province. A displacement along this line would account for the earthquakes described in Charts VI, X, XIII, XV, XVI, XIX, XXIII,(400) with their epicenters apparently around or in the northern part of Manila Bay. It is a contact line between andesite and the alluvium of the central plain, and between Tertiary sedimentaries and igneous rocks in La Union Province. Faulting is evident at many points along

* Manuscript report, see page 261.

this line. Mount Halcon, the large andesitic stock (elevation, 2,585 meters) in Mindoro, is also situated on or near such a line. Other suggestions occur when this line is prolonged southeastward.

Line *g–g*, which has been called "The Taal Volcano line," after Pratt,(478) starts from the northwestern part of Mindoro and in a nearly northeast direction crosses Taal Volcano, the western portion of Laguna de Bay, extending into the eastern cordillera, east of Manila, and thence runs toward Baler and Casiguran Bays. The southern portion of this important line from Mindoro Strait to Laguna de Bay has been accurately identified; while the probability of its continuation across the eastern cordillera toward the Pacific has been demonstrated by Saderra Masó. This line passes through the epicenter of Manila, located in the eastern cordillera, east and east-northeast of this city. If prolonged southwestward it passes close to the edge of the shelf on the west side of Palawan.

Line *h–h* cuts through the Dapitan epicenter, and three others which lie close to it. It also follows approximately the long axis of Cebu, where many large faults have been traced, and of Zamboanga Peninsula; but it is drawn west of the axis of Zamboanga Peninsula, as it is believed that some earthquakes have originated from displacements along the west coast of this peninsula. There is topographic and hydrographic evidence pointing to considerable faulting between Negros and Cebu. Tañon Strait, according to Dickerson, is due to a down-faulted block, though Smith thinks faulting is not the whole story.

Line *i–i* passes through three epicenters and along very important structural lines in the Archipelago. Beginning at the north it passes along the cordillera of Catanduanes and south through an epicenter located near the southern end of Leyte. The straits between this island and Samar may be controlled by this line. From here it extends through Butuan Bay, thence traversing very closely the structural line of Agusan Valley in Mindanao, and finally emerges from Mindanao near Cape San Agustin. Very little is known about the geology of the parts of the Archipelago traversed by this line.

Agusan Valley is very clearly a structural valley, probably a fault trough, as indicated by Mr. Graham B. Moody, recently in that country. What the condition of the rocks is with depth is not known, as the alluvial filling in the Agusan trough conceals much of the underlying formations. This line is one of the

most important in the Archipelago and has been described in previous articles.(412) In the first of these, Saderra Masó says:

> We call this line the line of the Agusan River Valley, because *the portion of it which lies within the said valley has been the seat of the greatest number of violent earthquakes which have occurred during the last fifty years.* The first seismic district of importance of this line comprises the large gulf of Davao, 120 kilometers long and 50 to 70 kilometers wide. The average depth of this basin is 800 meters, increasing however, towards the southeast in such manner as to exceed 1650 meters west of Cape San Agustin. To the west of the gulf rise the gigantic Apo Volcano, Matutan, and several other cones of less importance, which continue the northern boundary of the volcanic zone, extending, as it seems from Mt. Apo as far as the Celebes. The extensive valley of the Agusan River runs from southeast to northwest, almost parallel to the east coast of Mindanao. * * * The entire bottom of the Agusan Valley consists of marine sediments containing an abundance of recent shells. Only at the mouths of the water courses which descend from the mountains, bounding it east and west, is found gravel containing well worn pebbles of andesite and other igneous rocks. Every geologist who has visited this part of Eastern Mindanao receives the same impression, to wit, that its emergence from the sea is of quite recent date and its elevation is still increasing. Some of them assigned the Post-Pliocene period as the epoch of the formation of the sediment found in the Agusan Valley. This valley and the Davao Gulf appear to be portions of one and the same synclinal.

The somewhat sinuous line *x*–*x*, of the Philippine deep, clearly marks one or more great faults.

Numerous other lines might be suggested, but we have included all for which we have any geologic basis, and which appear to be necessary to explain many of the seismic phenomena of this region.

DISCUSSION OF IMPORTANT EARTHQUAKES

In discussing the various important earthquakes little will be said about any previous to 1870 save the greatest, which occurred in 1645; only the most important of those represented in the charts will be considered here.*

Earthquake of 1645, Luzon (3–9).†—This earthquake compares in magnitude with the greatest mentioned in the history of the world. Its meizoseismic, or epicentral, area was not less than 490 kilometers from north to south; that is, from the southern coast of Batangas and Tayabas to the northern part of Cagayan. On the western coast it seems to have been of less intensity; at least, the chroniclers of the time are silent about its effects in these parts, while they deal very largely

* See charts in La Seismologia en Filipinas.

† Numbers in parentheses refer to fig. 16 and indicate the location.

with the destruction caused in Manila and neighboring provinces of the south, east, and north, and the tremendous effects produced as far north as Lal-lo, in Cagayan Valley, and in the eastern part of the Cordillera Central, that is, in the Mountain Province. That such an earthquake was due to tectonic movements there cannot be the slightest doubt; furthermore, it is certain that its origin was along a north and south line, and that this line was within Luzon and not beyond its eastern periphery; it may be reasonably supposed that it was along the seismotectonic line *b–b*. The question arises whether the dislocations which then occurred along that line or fault were of such proportions as to be responsible for the many singular topographic features that now exist along it in Nueva Ecija, Nueva Vizcaya, and Isabela Provinces. Moreover, as in that memorable earthquake Manila seems to have been very close to its origin, our opinion is that some dislocations occurred at the same time along the fracture represented by the line *g–g*. Many instances are on record of the occurrence of severe earthquakes at the intersection of such lines.

The many earthquakes that occurred in 1871 were of volcanic origin, having as their epicenter Camiguin Island. The destructive area included Camiguin, Bohol, that part of Mindanao known as Misamis, and the southwest corner of Leyte.

Earthquake of June 3, 1863.—This was a very disastrous earthquake, comparable to that of 1645. It destroyed the Cathedral in Manila, burying in its ruins about twenty persons, most of them ecclesiastics, and almost destroyed forty-six public buildings and churches. The private houses destroyed numbered five hundred seventy, and the damaged structures exceeded one thousand one hundred seventy-two. Over four hundred people perished, and conservative statistics give two thousand as the total number of persons injured in Manila and neighboring towns. The meizoseismic area comprised the Provinces of Manila, Bulacan, Morong (Rizal), Laguna, and eastern Cavite. Fissures in the ground were reported from Bulacan. In Manila the greatest damage to private houses occurred along and near the river. The axis of the meizoseismic area followed the direction of the eastern cordillera.

Earthquakes of May 1 (7, 8) and of July 5, 1877 (10, 11).—The former was felt over most of southwestern Luzon, probably emanated from Taal Volcano, and probably was due to movements propagated along the line *f–f*, which follows the western limit of the central plain of Luzon. The latter may have been

of volcanic origin, as the whole southeastern volcanic region is comprised in the destructive area; or it may have had its origin in some movement along the line *x–x* marking the Philippine deep. This earthquake seems to have affected the whole of Panay, and was probably due to rockfall, because a recent examination has shown that landslides of considerable magnitude are of frequent occurrence on that island. In this region violent earthquakes of like character, and probably of the same origin, occurred in 1902 and 1904.

Earthquake of 1892, Pangasinan, Benguet, and La Union Provinces (*5*).—The tectonic nature of this earthquake seems to be beyond doubt, since it occurred in a region where no recent volcanic formations are to be found. The northern part of its epicentral area comprises the uplands of Baguio, where the tremendous upheavals that occurred in recent geologic periods are clearly evident. Almost in the center of the epicentral area rises Santo Tomas, an andesite block mountain due in part to faulting, while in the southern part lies the alluvium of the Pangasinan plains. It seems highly probable that the cause of the earthquake can be found in some important dislocation which occurred near the Santo Tomas mountain mass. This epicenter belongs to line *c–c*.

The earthquake of 1893, Agusan Valley, Mindanao (*20*).—This was unquestionably the greatest that occurred in this region during the last three centuries. The permanent sinking of part of the floor of the valley and the faulting on the divide between the headwaters of Agusan Valley and Davao Gulf suggest a movement of the eastern cordillera as a whole, or a slip toward the east, in connection with the changes which possibly occurred in the deep trough running along the east coast. Therefore, this earthquake must be classified as most typically tectonic, as it occurred along a very definite structural line.

Earthquakes of 1897.—The natural and fearful happenings of this year bring to mind the somewhat fabulous occurrences of 1641, when earthquakes in Luzon occurred at the same time as eruptions in Mindanao, Jolo, and Sangi. During this year destructive tectonic earthquakes were felt in northern Luzon (2), northern Samar (11), Masbate (12), eastern and western Mindanao (19, 22, 23, 24) and, as a climax, Mayon Volcano had one of its worst eruptions. The most typical and important of these earthquakes was the one that occurred in western Mindanao. Its origin or epicentral area seems to have been

under the sea, west of Zamboanga Peninsula, on the *d–d* line. It must be considered as one of the most memorable of Philippine earthquakes on account of the most extraordinary seismic wave ever noticed in the Archipelago. Furthermore, it seems to have been connected with the rising of some temporary islands near the northwest and the northeast coasts of Borneo.

Earthquake of 1902, Illana Bay, Mindanao (*23*).—This earthquake heavily shook Cotabato and Lanao districts. Its epicentral area comprised part of the bay, where the telegraphic cables were broken and buried under mud, the eastern coast and plain of Cotabato, and the northern coast of the uplands of Lanao district as far as the lake. In the latter region there was great volcanic activity during the Tertiary period, as is shown by the basalt and lava flows which cover it, and some old volcanic cones that rise toward the south and east; but, during the historic period, only one doubtful eruption is reported. Consequently, considering the wide extension of this earthquake and its effects upon land and the bottom of the sea, it should be classified as tectonic, and connected with a possible line indicated by Cotabato River.

Earthquakes of January 29 to 31, 1911, southeastern Luzon.—Four hundred ninety-eight earthquake shocks were recorded in Manila during the twenty-four hours of the last great eruption of Taal Volcano. Most of southeastern Luzon was affected. These were all of volcanic origin.

Earthquake of July 12, 1911.—This most violent earthquake, in the central part of Agusan Valley, was felt throughout the whole of Mindanao, Sulu, the Visayas, and as far as Palawan (?). Its meizoseismic area extended from central Agusan eastward to the Pacific deep. This was clearly tectonic in origin.

Earthquakes of August 23, 1913, Baguio, Luzon.—Severe earthquakes were experienced in this region during the height of the rainy season of 1913. They undoubtedly can be traced to displacements along such faults as the one mapped years ago by Eveland, along the escarpment of Mount Santo Tomas.

PRACTICAL CONSIDERATIONS

There are three things that must be done in order to cope with earthquakes; the most obvious is in the line of engineering. In building structures they must be so tied together that the parts will not fly into fragments, and the material must be elastic. The safest and cheapest type of construction is the Malay house of bamboo wherein rattan takes the place of nails. Sand-lime

brick securely tied to a steel frame, and reënforced concrete are the most suitable for large buildings. Volcanic tuff (locally quarried as Guadalupe stone) is one of the best cheap materials. The walls and many of the older public buildings of Manila are constructed of this stone.

Aside from the class of building material to be used, there is the all-important question of the nature of the ground on which large structures may be safely erected. The investigations of the California Earthquake Commission revealed very conclusively the dangers from "made ground" in regions subject to earthquakes. Nevertheless, in spite of their findings, of which any up-to-date engineer ought to have knowledge, we see in Manila large five- and six-storied structures (it is true they are of reënforced concrete) being erected on made ground or on river alluvium which is none too stable. Buildings of the sky-scraper type, such as the Luneta Hotel, are very ill advised. Piles and test borings have not been able to reach bottom on the Luneta. Practically the whole of Manila is located on loose sand saturated with water. In such material large structures are subject to settling, and they do settle. Furthermore, since seismic waves travel with the greatest acceleration and amplitude in loose formations, the displacement due to earthquake motions is greatest on ground of this kind. Three or four stories ought to be the limit of height for buildings in Manila. The city engineer of Manila tried for some time to have an ordinance passed limiting buildings to five stories, and finally succeeded. Such height is certainly the absolute limit of safety in this country.

SEASONAL DISTRIBUTION OF EARTHQUAKES IN THE PHILIPPINES

Following the suggestion of M. G. Zeil,(663) formerly of the topographic service of Annam, we find that the 2,967 shocks felt in the Archipelago from 1902 to 1920, may be divided into four groups: Western Luzon and the Visayas; eastern Luzon and the Visayas; western Mindanao; and eastern Mindanao. Their distribution by months and comparison with the rainfall of these periods is given in Table 21.

The total number of shocks as shown in this table exceeds the actual total number because central earthquakes have been credited to both the west and the east.

If we represent graphically the above monthly values and compare the variation resulting with the rainfall variation graph of Dagupan or Manila, or any other western station having a typical distribution of cyclonic rainfall, we do not find

close parallelism; but the tendency to parallelism exists, except for the months of June, July, and August.

TABLE 21.—*Monthly distribution of Philippine earthquakes and rainfall.*

[Total, west, 898; east, 2,069.]

Month.	Luzon and Visayas.		Mindanao.		Rainfall.	
	West.	East.	West.	East.	Dagupan.	Legaspi.
	Shocks.	*Shocks.*	*Shocks.*	*Shocks.*	*mm.*	*mm.*
January	46	93	19	101	10	376
February	49	75	21	85	21	373
March	42	101	17	95	29	171
April	58	80	7	59	91	126
May	82	102	7	74	256	134
June	65	95	11	73	293	207
July	55	93	15	102	567	231
August	59	89	22	102	472	172
September	75	70	21	78	472	251
October	76	93	23	77	209	329
November	57	88	12	83	61	349
December	39	84	20	77	20	488
Total	703	1,063	195	1,006		

The figures for the eastern part of the Archipelago are still more capricious, presenting a rather complete discordance between the numbers of earthquakes and the amounts of rainfall. The same is found with the number of the Mindanao shocks, there being a tendency to divergence between rainfall and shocks.

As was to be expected, the number of shocks, both in Luzon and the Visayas and in Mindanao, is far greater for the eastern than for the western regions, instability increasing with the proximity to the edge of the continental shelf.

It is possible, of course, that the greater amount of rainfall in the east has some effect. In fact, if we consider the results of rainfall observations, as published recently by Coronas, it will be found that the northeast monsoon rainfall for the eastern portion of the Archipelago is generally more copious and persistent than the cyclonic rainfall watering the western portion. The average number of rainy days is greater and the amount, above 3,000 millimeters, covers more-extensive regions in the east than in the west.

In support of Zeil's theory it might be mentioned that the central Visayas (Negros, Cebu, and Bohol) are as nearly short of shocks as they are deficient in rain.

If we consider the 2,129 seismic disturbances, perceptible or otherwise, recorded by the seismographs of Manila, and the 5,167 of Butuan during the last five years (1916–1921) with their monthly averages, the distribution shown in Table 22 is discovered.

TABLE 22.—*Monthly distribution of earthquakes and rainfall at Manila and at Butuan.*

Month.	Manila.		Butuan.	
	Shocks.	Rainfall.	Shocks.	Rainfall.
		mm.		*mm.*
January	40	21	93	246
February	35	12	79	204
March	32	19	101	167
April	35	48	65	133
May	40	113	71	156
June	37	202	64	166
July	41	457	93	123
August	37	369	101	106
September	37	358	80	143
October	37	186	90	162
November	29	108	104	250
December	26	71	99	295

In the totals for Butuan the numerous aftershocks following two great earthquakes have been omitted.

The distribution of these disturbances shows more nearly a tendency to follow the distribution of rainfall. Manila shows high numbers in July, while for Butuan the peak is reached in the last months of the year; still, no certain generalization can be made from those data in favor of Zeil's theory. It should also be pointed out that the trigger effect * of changes in barometric pressure and not the rainfall might be the controlling factor, since the greatest deluges of rain come in the typhoon periods.

* The trigger effect is possible in the west but not in the east, where the rainy season comes with high barometers without typhoons.—M. S. M.

VOLCANOLOGY

A summary of the subject of Philippine volcanoes as known in 1900 and their relation to those of Malaysia is given by Becker.(50) Koto(360) presents a suggestive map and comments on the volcanics of the Malaysian region. Becker had an advantage over Koto because the latter had never visited the Philippines.

Becker's very clear and large view of the relation of the volcanic belts in the Malaysian region is so much better than anything I can contribute on this subject that an excerpt from his chapter is included here.

So large a portion of the Philippines consists of volcanic rock as to make it manifest that there must be in the archipelago a considerable number of volcanic belts. Such zones form one of the most prominent features of Malaysia as a whole, and when these are passed in review it appears that the volcanic structure of the Philippines must bear complex and interesting relations to that of the entire region. J. D. Dana was, I believe, the first to call attention to the linear disposition of the volcanic islands of the Pacific and to refer this arrangement to geotectonic principles. Naumann, Perry, Suess, Junghuhn, Centeno, Wichmann, Verbeek, Martin, Molengraaff, Koto, and others have contributed to the subject, which, however, still requires much study, especially with reference to the Philippines.

The Nicobar Islands, Sumatra, Java, and the Little Sunda group lie along the edge of a vast submarine precipice, or, in other words, at the very abrupt limit of the continental plateau. Lines of folding and volcanoes, Tertiary and modern, accompany the course of this southern limit of Asia. Some of the most active and remarkable volcanoes of the world are here. Papandayang, in West Java, had a great eruption in 1772, destroying 40 villages. Galung Gung in 1822 destroyed 114 villages; and it is some measure of the violence of the Krakatoa explosion of 1883 that over 36,000 people perished. Off the eastern coast of the Philippines there is also a rapid deepening of the sea bottom, marking the eastern edge of the continental plateau, and here, too, there is a series of active or extinct volcanoes which stretches from close to Formosa southward to the Moluccas. According to Naumann, these two great lines meet in the volcanic island of Nila, about latitude 6° 30′ S., longitude 129° 35′ E., but later studies show that, while in a generalized way this statement represents the distribution of the main volcanic lines, the volcanic systems of the Banda Sea are very complex. In this neighborhood submarine elevations connect Malaysia and Australia, and complexity of structure is therefore to be expected. As many as three curved folds appear to exist here with a common center near the middle of the Banda Sea. They certainly serve to connect the Sunda volcanic line

with the Formosa line; but, though considerable study has been devoted to the subject, the evidence is not sufficiently full to unite geologists as to the actual linear connections between volcanic localities. The Formosa line seems clearly to continue along the eastern coast of the Philippines southward through Gilolo, in the Moluccas, but Koto and others regard Buru and Ceram as a recurved portion of one of the concentric Banda Sea arcs, and as running in this locality perpendicularly to the Formosa line. For the present purpose it is not needful to enter into minutiae concerning the Banda Sea area.

Within the region outlined by the submarine cliffs of the continental plateau and by the great volcanic arcs lie Borneo, Celebes, and the western portion of the Philippines, as well as the peninsula of Malacca and its continuations, Bangka and Billiton. These latter are closely connected, structurally and otherwise, with the Nicobars and Sumatra, and they are of minor interest so far as the Philippines are concerned. On the other hand, a glance at such a map as Stieler's physical map of Asia is sufficient to show that Borneo, Celebes, Gilolo, and the Philippines are very nearly related from a structural point of view. The southwestern ranges seem to gather in toward the eastern edge of the Philippines as do the branches of a tree to its trunk. The eastern coast range of Mindanao is continued southward, by the Talaut Islands and others, to Gilolo in the Moluccas. Near the center of our own Island of Leyte there is a fork in the mountain system, and the westerly branch is seemingly continued southward, through Mount Apo and the southernmost point of Mindanao, by way of Sanguir Island to Celebes. In the Visayas, at Masbate, it would seem that a second branch is thrown off, extending through Negros and Western Mindanao, Basilan, and the Joló group to the Bornean coast. More obscure is a line which starts apparently in Panay and is marked in the Joló Sea by the Cagayanes, including Cagayan de Joló, for which the Government of the United States is now negotiating with Spain. A very important line is represented by the Calamianes and Palawan, continued in Borneo by the range one point of which is the lofty Kina Balu, which is not volcanic. This range extends through Borneo to its southwest coast and, in the opinion of some geologists, not including Mr. Verbeek, there connects with Bangka. In northern Luzon the coast range or Sierra Madre is clearly continued by the Babuyanes and Batanes to the neighborhood of Formosa (or Taiwan), but the relations of the Zambales Range and the Caraballo del Norte are not evident on mere inspection.

With reference to the connection between Formosa and the Philippines referred to by Becker I have called attention elsewhere to the probability that the eastern side of Formosa may be structurally continued by the western side of Luzon.

Saderra Masó contributed a chapter on volcanoes to the first Philippine Census.(404) Ferguson began an extensive paper on Philippine volcanoes but never completed it, and his notes have been used to some extent in writing the following pages. Pratt(478) published an excellent report on Taal Volcano; and Worcester(650) has written an excellent popular article on the

same subject. Upon all of these I have drawn for the compilation of this chapter, and to all of these men I am much indebted. I have also drawn upon my own notes, made in other studies not especially connected with the subject of volcanism. Special studies by the two Spanish geologists Abella and Centeno, prior to American occupation of the Islands, should also be mentioned.

The Philippines form a part of the "Circle of Fire," which follows the periphery of the Pacific Ocean and contains within its territory the well-known Taal Volcano, which was very destructive in 1911; Mount Mayon, perhaps the most perfect volcanic cone on the surface of the earth, which was in eruption in 1902; Mount Canlaon, which was in eruption in 1904; Camiguin de Mindanao, which is chronic in its manifestations; and many extinct and dormant vents.

A list of all the active and solfataric volcanoes is given in Table 23, which is revised from the one published by Saderra Masó in 1903. It is interesting to note here the recent activity in the Sangi Islands, a group south of Mindanao that links the Philippine Archipelago with Celebes.

This list of active and dormant volcanoes could be greatly augmented by adding a host of more or less eroded cones, some of which are to be referred to the Pliocene and Pleistocene rather than to the Recent. However, we must remember that erosion proceeds in the Tropics far more rapidly than in more temperate regions, and therefore they may not be so ancient as they seem. In this class are such prominent volcanic stocks as Mount Arayat, in the central plain of Luzon; Mariveles, at the entrance to Manila Bay; Mount Pinatubo, the highest of the Zambales Range; Mount Banahao (Plate 22), in Luzon; Mount Halcon, in Mindoro; and Mount Malindang, in Mindanao.

The salient features of each of the more-important volcanoes will now be considered but the discussion will be condensed considerably.

MOUNT APO

This mountain is situated in 7° 3′ north latitude, and longitude 125° 17′ east of Greenwich. The highest point attains an elevation of 9,610 feet which is the final United States Coast and Geodetic Survey figure as a result of recent triangulation. The old elevation of 10,311 feet on Spanish charts was first shown to be in error by me, when I obtained the figures 9,690 feet by hypsometer in January, 1908. This mountain is located comparatively near the sea and a few kilometers south of the little

town of Davao, Mindanao. Plate 31 is from a photograph taken from Digos, the coast town at the foot of the long ascent to Mount Apo.

TABLE 23.—*Active and solfataric volcanoes with their locations, heights, and dates of eruption.*

[Revised by Miguel Saderra Masó.]

Volcano.	Province.	Approximate-				Height.	Rock.	Date of eruption.
		Latitude.		East longitude.				
		°	′	°	′	*Meters.*		
Babuyan	Cagayan	19	30	121	56			1831, 1860, 1919.
Camiguin	do	18	55	121	52			Solfataric.
Didicas	do	19	2	122	9	700		1856 to 1860.
Caua, or Cagua	do	18	13	122	1	3,920		Solfataric in 1860
Taal	Batangas	14	2	120	57	1,050	Andesite	1709, 1715, 1716, 1731, 1749, 1751, 1808, 1873, 1904, 1911.
Mayon	Albay	13	16	123	39	7,916	Andesite	1616, 1766, 1800, 1814, 1827, 1835, 1845, 1846, 1851, 1853, 1855, 1858, 1868, 1871, 1872, 1873, 1881, 1885, 1886, 1887, 1888, 1890, 1891, 1892, 1893, 1895, 1897, 1900, 1902.
Bulusan	Sorsogon	12	47	124	1			1852, 1916, 1918, Solfataric.
Canlaon	Oriental Negros,	10	25	123	6	8,912	Andesite	1886, 1893, 1904.
Do	do	9	15	123	9		do	Solfataric.
Camiguin	Misamis	9	12	124	42	1,950	do	1871, 1875.
Apo	Davao	7	3	125	17	9,610	do	Solfataric.
Ragang	Lanao	7	10	124	29			1915.

Saderra Masó has published, in the Philippine Census, a statement of the early explorations of the peak. It is interesting to note that two Jesuit priests ascended the mountain in 1888 in order to secure magnetic observations for a general magnetic chart for the whole of Mindanao.

Dr. E. B. Copeland, the first American who ascended the mountain, placed a steel cylinder for records in a cairn at the summit of the highest peak of the cluster. In the four years between that time (1904) and my ascent (1908) no others had been on the summit; at least, no record was found.

On the east side of the mountain, 300 meters below the summit, is a great crevasse along which are located several large sulphur vents. Near the coast this sulphur might have a commercial value.

As one ascends the trail from the coast to the summit, he finds that the character of the formation changes from an agglomerate near the base, in the region of the explosion crater (already referred to as existing to the northeast), to flows of andesite on the main peak. It seems as if the history of this mountain has been as follows:

There was formerly a great volcano, upwards of 4,000 meters in height, where the old explosion crater now is, which, after the cone had been built up to at least 3,000 meters, poured out lava, some of which can be seen on the present high point known as Apo; later, in a tremendous explosion, the large cone blew its head off, so that now it is a truncated and much lower cone, leaving Apo standing up as if it had always been the focus of activity. On the present high peak is a cirquelike depression which undoubtedly marks the existence of a former active crater. This volcano is in the solfataric stage, with a considerable number of sulphur vents on its slopes.

TAAL

Taal Volcano, the best known of the volcanoes in the Philippines, is located on a small island near the center of what appears to be a large crater lake, Lake Bombon, in Batangas Province, about 50 kilometers due south of Manila; to be exact, in latitude 14° 2′ north, longitude 120° 57′ east of Greenwich. The highest point on the crater rim is about 400 meters. The main crater is nearly circular, having its longest diameter east and west, amounting to 2,000 meters. There are several subsidiary craters on this island, all of which have been comparatively quiet in recent years. The large crater is now filled to the level of the lake outside with water and mud. This was fairly hot for some time after the last eruption, but is no longer so.

On January 30, 1911, occurred the last great explosion of this historic volcano. Plate 16 shows the volcano in eruption. Figs. 17 and 18 are plans of the crater before and after the eruption, respectively. These illustrations are taken from Pratt's report.(478)

This crater has probably never ejected any material other than fragmental ash and bombs. There is no sign of lava anywhere about the island. The ejecta are largely basaltic. Consider-

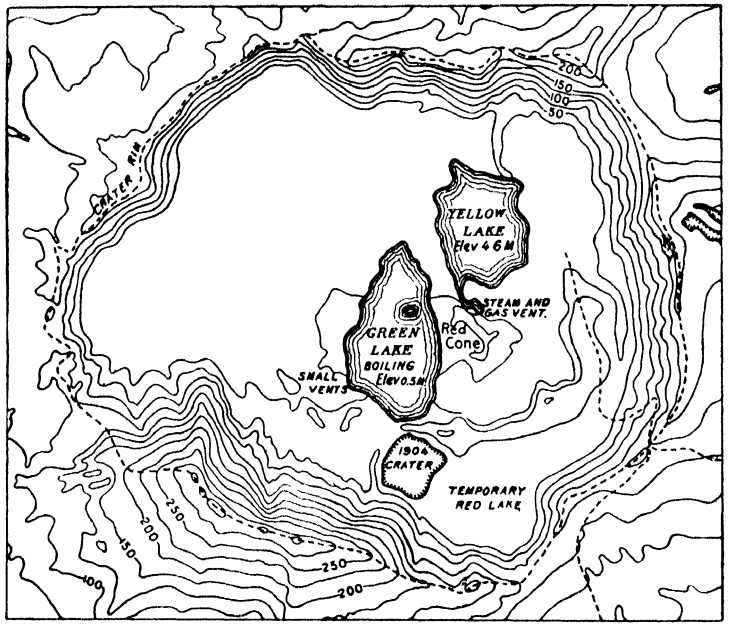


FIG. 17. Map of the crater of Taal Volcano prior to January 1, 1911; from a topographic map by S. B. Coleman. Scale about 1 : 25,000.

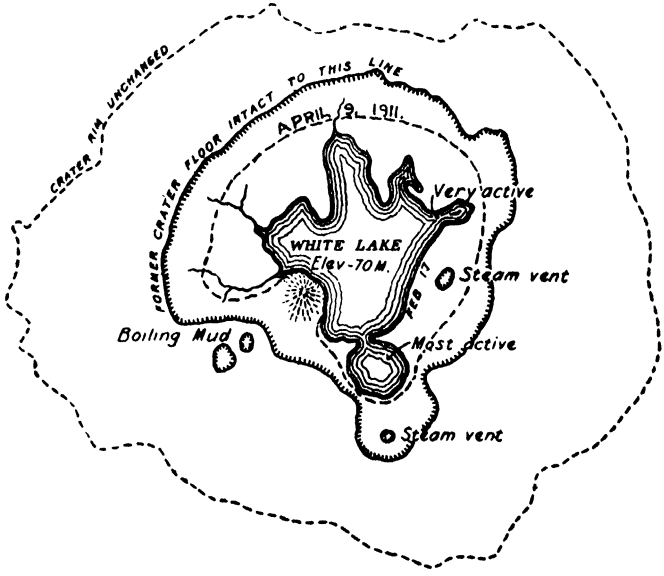


FIG. 18. Sketch map of the crater of Taal Volcano made February 17, 1911; the great eruption occurred on January 30, 1911. Dotted line shows contour of crater lake on April 9, 1911, as observed by W. D. Smith. Scale about 1 : 25,000.

able petrographic study has been made by various scientists, among them Oebbeke(462) and Iddings,(337) of the basalt from the vent. Iddings's description is given in the chapter on Petrography.

The following paragraphs are some of the more-important conclusions about the salient features of the 1911 eruption, which were prepared at the time by Pratt:

Evidence has been gathered showing that Taal Island, around its perimeter at least, subsided during the recent activity through a distance varying from 1 to 3 meters. This point has been disputed in the [Manila] daily press. The lake level relatively to its shores has been lowered, due in part, of course, to the subsidence of the island at its center, though probably other movements have been contributing causes. The whole lower part of the Pancipit River Valley subsided from 1 to 3 meters, the ocean tides actually flowing over about 1 kilometer of macadamized provincial road west of Lemery.

The movement and action of the eruption cloud which burst from the crater at the culmination of the activity, afford an interesting study. To the people who watched it, this cloud appeared only to rise and when far above the earth to spread out like a great umbrella. There is strong evidence, however, that it expanded and traveled in every possible direction, down as well as up, from the moment it was released from the crater. As a consequence it wrought its greatest destruction as it swept down the slope of the mountain and out across the surrounding lake. It was only the area lying around the volcano over which this explosive expansion was felt that suffered devastation. Where the gases (principally steam) had reached their full volume under atmospheric pressure only a gentle fall of mud occurred.

The height to which the eruption cloud attained at the time of greatest activity has been a popular subject for speculation. The evidence noted during this investigation tends to show that the cloud was at least 3,000 meters and probably less than 5,000 meters high.

The materials ejected were (*a*) steam; (*b*) volcanic tuff which was ground to a fine sand or ash by the friction of its particles in the air, and wetted to mud by the steam; (*c*) large blocks of bedded volcanic tuff (adobe stone); (*d*) some homogeneous volcanic rocks, a few of which were heated to incandescence; (*e*) a relatively small volume of sulphur dioxide with perhaps some other gases; and (*f*) water.

Except for the few incandescent stones, the material thrown from Taal was not much hotter than the steam which accompanied it. Even on the volcano slopes neither vegetation nor the clothes of the victims were burned or even scorched. The burns on the wounded were in many cases the result of scalding steam and the abrasion of the wound by the terrific blast of mud (sand). This sand blast was intense enough actually to shred and cut away the bark of large trees.

The magnificent electrical display which many watched from Manila was probably due to the discharge of electricity generated by the intense

friction within the cloud itself and apparently all the glow and light of the eruption (except that of the small number of incandescent stones) was due to the reflection of this lightning from different parts of the cloud. There is no evidence of the presence of inflammable gases in the eruption cloud.

The system of earth fissures which opened during the activity has been mapped in detail and the result throws important additional light on the study of the volcano. These fissures, with the geyserlike springs that spouted, and mud craterlets which were built up, along the main fissure at a distance of 18 kilometers from Taal itself, are interesting phases of volcanic activity, and merit close study. It should be stated that the towns of Taal and Lemery are so located as always to be subjected to the maximum intensity of earthquakes that occur in connection with the eruptions of Taal Volcano, and probably earthquakes which affect southwestern Luzon independently of volcanic action. The suggestion of moving these towns should receive serious consideration.

One of the most striking features of the eruption, and one which interests people who have visited the volcano, is the change wrought in the volcano itself. Outwardly, Taal is little changed by its late activity but the interior of the crater is startling evidence of the magnitude of this eruption.

Throughout historic time all descriptions of Taal have mentioned the Yellow Lake and the Green Lake, two small bodies of water which lay within its crater. These have remained practically unchanged through the severest eruptions in history up to the present. Now, however, the crater contains only a single large, deep lake whose water (owing to suspended sulphur) appears milky white. More significant, even, are the relative levels of the old lakes and the new. The former lakes stood just above sea level. On February 17, when the new crater was mapped, this White Lake stood approximately 70 meters (230 feet) below sea level. This change in elevation is evidently not due to subsidence, but to the removal of material from the old crater.

Great streams of hot water (150 cubic meters per minute) were pouring into the new crater from its walls and the new lake was growing rapidly. Examination indicated that this water seeps through the crater walls from Lake Bombon which encircles the volcano. On the west shore of the white Lake is a great pillar or neck of basaltic material, fragmental near its summit but massive-appearing below. This natural obelisk is perhaps 70 meters (230 feet) in diameter and on February 17, stood about 115 meters (375 feet) above the crater lake. The top of this rock is approximately on a level with the former floor of the crater.

The volume of solid ejecta coming from Taal during its late activity is approximately 70,000,000 to 80,000,000 cubic meters. The area over which this fell to a thickness of more than 1 millimeter is about 2,000 square kilometers. The maximum thickness of fall (except where drifted) is 20 to 30 centimeters. The area over which the direct action of the volcano was violent enough to kill men and large animals and to uproot or break off large trees is approximately 230 square kilometers.

The approximate volume of material torn out and removed from the crater of the volcano above the level of the new lake is 45 million cubic meters. If this material (compact bedded tuff) were ground up and spread out as a thin layer of relatively loose volcanic mud, it would occupy about one and one-half times its former volume or nearly 70,000,000 cubic meters.

Thus, there is accounted for practically the whole volume of material which was ejected, allowing only a very reasonable depth for the White Lake. Since many of the large pieces of ejecta were fragments of bedded tuff it may be reasonably concluded that practically all the material thrown out during this eruption came from very near the surface. The only ejecta to which even a moderately deep-seated origin need be assigned are the few incandescent rocks observed. There is evidence that even these were originally thrown out by the volcanic activity of former ages and only "worked over," as it were, recently.

The formation of the large lake in the crater (this lake will probably continue to rise approximately to sea level) has been taken to mean either that Taal is extinct, or that another eruption must result very soon. Neither of these extreme effects seems at all likely. Among the world's authorities on volcanic action many, perhaps a majority, believe that meteoric water (water condensed from vapors in the atmosphere) even though it penetrates to the greatest depths possible for it to attain, has only a very minor part in volcanic phenomena. Certainly, this surface lake, occupying the very top of the volcanic throat, can have little effect on the real source of Taal's activity.

It should be evident, however, that replacing 50,000,000 cubic meters of resistant, inelastic, heat-insulating earth with a like volume of perfectly yielding and almost perfectly heat-conducting water will dissipate more rapidly the volcanic heat which reaches the upper part of the volcano throat, and will tend to relieve stresses which might formerly have resulted in minor violence.

The magnitude of this eruption of Taal has been both exaggerated and belittled. Consequently it is of interest to compare it briefly with a great volcanic eruption.

In May, 1902, Mount Pelee devastated an area of 32 square miles (83 square kilometers), killed 30,000 people, and spread ashes (in one direction at least) over a radius of more than 100 miles (160 kilometers). A large proportion of the ash which it threw out was incandescent, burning and scorching vegetation and wooden structures. The crater of Mount Pelee is about 4,200 feet (1,280 meters) high.

Recently Taal exerted a devastating violence over an area of approximately 230 square kilometers (part of this area was lake surface; the land surface devastated was about 98 square kilometers). The greatest distance from the volcano at which an appreciable depth of ash fell was about 42 kilometers, and the number of people killed was 1,332 (official estimate).

Thus, Taal devastated a greater area than Pelee, yet it spread its ash over an area probably less than one-tenth as large. This apparent inconsistency can be satisfactorily explained. The barrio of Gulod is approximately the same distance from the crater of Taal as Saint Vincent (where most of the loss of life occurred) was from the crater of Mount Pelee and, like Saint Vincent, was in the path of greatest volcanic [destructiveness] of the eruption. In Gulod 116 people were killed out of a total population of 120, and this proportion would probably have been the same if 26,000 people had been living in Gulod, as there were in Saint Vincent. [In this paragraph Saint Vincent should read Saint Pierre.]

On the whole, the recent eruption of Taal, while probably of decidedly lesser magnitude and intensity than that of Pelee in May, 1902, was

strikingly similar in character and will undoubtedly rank among great volcanic eruptions of modern times.

Chemical studies on the ejecta from this eruption were published by Cox.(160) For some conclusions as to the effect on the seismology of the region, see the chapter on Seismology.

The origin of Lake Bombon, which surrounds Volcano Island, has long been a matter of conjecture on the part of geologists. Adams(21) has made the suggestion that the lake is due to peripheral faulting and scouts the idea expressed by earlier writers that it marks the site of a large mountain which either blew off its head or collapsed. From my own observations at Kilauea on Hawaii, where peripheral slicing and faulting have very evidently caused the formation of the great caldera inclosing the smaller pit of Helemaumau, it would seem that Adams's view is probably the most nearly correct of those advanced to date.

Saderra Masó, who has charge of the volcano observatory at Taal, discusses the work of that institution as follows:

After the last eruption of Taal Volcano in 1911, it was decided to build a volcano station as near as possible to its main crater. But as the Taal craters are located in an island built up by eruptions of an explosive character, consequently consisting of movable and soft materials, located in the middle of a broad lake, the proposed station had to be placed on the nearest and most accessible shore of the lake, where hard old banks of tuff offered a stable base. Outcrops of solid lava of basalt nature if any, are found at great distances from the volcano. The primary object in mind of the Director of the Weather Bureau in establishing and operating such a station was to watch the changes in the activity and interior strain of the volcano; so his first care was to set up a very sensitive seismograph of the Vicentini type, to record micro-tremors. A motor-launch was also provided in order to facilitate regular visits of the observers to the crater, and occasional visits of tourists and scientists. It was also intended by the Government to warn the people living around the shore of the lake in case of an impending eruption. A continuous observation of the changes of level in the lake was also started, but it was found that frequent changes due to copious downpours of rain in a lake rather small and with a very narrow outlet interfered, and prevented securing any reliable data; these observations had to be given up definitely by the extraordinary quick filling and extending out of the shore near the station.

At present any analysis of the gases of the main vent is nearly impossible: as a consequence of the last eruption, its entire bottom was converted into a deep pool by the waters of the surrounding lake filtering through the soft and porous material of the island volcano; this great body of water seems to act as a powerful condenser of the heat and gases issuing from below; so much so that only some small vents are seen on the nearly vertical walls of the crater.

In fact the last eruption, which practically consisted of one tremendous explosion or blasting, probably was due to obstruction and directed to

the clearing of the materials which during nearly a century had been eroded from the walls and carried down by the heavy tropical rains reducing more and more the vents and at last nearly obliterating them.

An interesting paper by Brown, Merrill, and Yates(63) deals with the revegetation of Volcano Island (Taal) after the last eruption.

I revisited Taal Volcano on April 21, 1921, and found it inactive. The water in the crater lake was a dull greenish color, and no steam was coming from the lake as formerly. Only very insignificant gas emanations could be seen in two or three places along the inner walls of the crater. The island is entirely covered with talahib grass. No one is living on the island, though some horses, carabaos, and cattle are brought over in boats to graze on the rank grass.

MOUNT MAYON

I have been all around this volcano and on its slopes, but have made no detailed study of it. Abella(4) made the first systematic study of it, and Becker has summarized what Abella and others have written; therefore, we can do no better than to quote Becker's summary, as follows:

> Mayón, or the volcano of Albay, is, next to Taal, the most famous Philippine volcano. It is possibly the most symmetrically beautiful volcanic cone in the world, and at times its crater is almost infinitesimal, so that the meridional curve of the cone is continuous almost to the axis. The height has been variously determined, and appears to change with each eruption. Since the crater always remains small, the height should tend to increase, but the determinations are probably not sharp enough to develop this tendency. Jagor's barometrical measurement in 1859 was 2,374 meters. The Spanish Hydrographic Commission, according to Mr. Abella, gives 2,522 meters. Mr. d'Almonte's map of 1883 gives 2,527 meters. Mr. Abella himself gives 2,734 meters, but he did not reach the summit, because his visit was made during the eruption of 1881–82, and does not state his means of determining the height. Mr. d'Almonte, however, made a sketch map of the mountain for Mr. Abella's memoir, and I fancy that he measured the height by triangulation. In English measure Mr. Abella's elevation would be 8,970 feet.* The rock of Albay is described by Roth and von Drasche as dolerite, but Mr. Oebbeke regards it as an olivinitic augite-andesite.
>
> Albay has had a vast number of eruptions. Father Coronas gives some details as to eruptions in 1616, 1766, 1800, 1814, 1827, 1835, 1845, 1846, 1851, 1853, 1855, 1858, 1868, 1871, 1872, 1873, 1881, 1885, 1886–87, 1888, 1890, 1891, 1892, 1893, 1895, 1896, and he describes the eruption of 1897. According to the newspapers, there was an eruption early in 1900. Some of these

* The latest figure given is that on the United States Coast and Geodetic chart (1918) of 2,421 meters.—W. D. S.

eruptions have been very serious. In 1814 about 1,200 lives were lost (Jagor, by error of transcription, says 12,000), and the country was covered with ash. Many picturesque details may be read in Perry or elsewhere. Of more permanent interest than the destruction of life and property is the character of the emanations. Mr. von Drasche, adopting Stohr's hypothesis of three periods in the life of a volcano (first, that of lava flows; second, that of agglomerate flows; third, eruptions of ash), considers Mayon in the second stage, and says that the ash eruptions are seldom interrupted by small lava flows from the summit. Mr. Abella states from observation that the ash ejections are small and preliminary to extensive flows, and Father Coronas gives a map of the flows of 1897, when lava from the summit poured down in various directions, even reaching the sea at a horizontal distance of about 6 miles from the crater. In 1897, however, there was much ash as well as flowing lava. An area of about 4 square degrees was covered with ash, which, nevertheless, formed an orogenetically insignificant layer at points considerably removed from the foot of the mountains. At Tabaco, less than 10 miles from the crater, the inhabitants were reasonably in fear of smothering, but the ash which fell was only 3 or 4 centimeters in depth. Per contra, on the mountain side, the fall was heavy; the village of San Antonio, more than 4 miles from the crater, was so buried under lava and ash that the ridgepoles of the houses were hidden. It would appear from the descriptions that a very considerable part of Mayon consists of a solid framework of lava flows, which alternate more or less irregularly with ash eruptions, but that the external form of the mountain is determined by showers of ash and coarser fragmental ejecta. I can hardly believe that there is ordinarily any such regularity in the life-history of a volcano as is implied in Stohr's hypothesis. Study of the history of Mayon and comparison with other volcanoes show that the form of the vertical cross section is a definite one (depending on the resistance of the material to crushing), and it follows that the material ejected during any considerable eruption is so distributed that the vertical depth of the added layer is substantially uniform from the summit to the base. Of course, more material falls near the top than near the bottom, but more rolls down from the steeper slopes of higher portions than from the gentler slopes near the foot. If each particle were to remain where it fell the slope would become steeper at each eruption and the mountain would tend toward the shape of a cylindrical column.

Becker has made some studies on the curve of the slope of the volcano and has published the following formula as representing the mathematical equation of this sine curve:

$$\frac{y}{c} = \frac{e^{\frac{x}{c}} - e^{-\frac{x}{c}}}{2}, \text{ where } c = 8.6 \text{ millimeters.}$$

The last eruption of this volcano occurred in 1902, but it was not particularly destructive. Ashes and bowlders covered the new road between Legaspi and Libog. Here, again, the eruptions have been entirely of the explosion type. No lava can be seen anywhere around this mountain. In 1915 a great stream

of mud and stones came down the east slope of the mountain and again covered the Legaspi-Libog road.

CANLAON

Canlaon Volcano, its highest point at an elevation of 2,438 meters on Negros Island, is situated in latitude 10° 20′ north, and just north of the center of the island and about midway between its two coasts. No great eruptions from this volcano are recorded, but repeated minor ones have taken place, in 1866; 1893; in May and June, 1894; January 31, 1902; and the last, in 1904. McCaskey is the only member of the Philippine geologic and mining staff that studied the volcano but, unfortunately, he never published his results. One of his photographs of the crater as it was in 1904 is shown in Plate 32.

In the regional chapter on Negros Island there will be found some notes by Chas. S. Banks, of the Bureau of Science, who ascended Canlaon in 1902.

VOLCANOES IN ISLANDS NORTH OF LUZON

Of volcanic activity on the islands north of Luzon and on northern Luzon, Ferguson is the only one who has made any studies worth noting, and I have taken the liberty of making some extracts from an unpublished manuscript. Ferguson notes the extinct crater of Iraya on Batan, of which he says:

> This mountain is a beautifully symmetrical cone, its height as given on the Coast Survey chart being 3,806 feet (1,160 meters). The cone is of the Vesuvian type; that is, it is built up in large measure through explosive activity though lava flows form a considerable portion of its mass. Two rims of older craters are present, the oldest represented by a hill of tilted basalt on the southern side of the mountain and a later one showing a complete rim around the present cone. It is in this older crater that the present cone has been built up. A continuation of the curve of this older cone would give the mountain a height about 30 per cent greater than at present. The present crater is horseshoe-shaped, being broken down on the northern side where the last lava flow, a stream of basalt, has emerged. Numerous, small fissures, probably the result of earthquakes, are seen in the crater and one cuts across its southern wall. These fissures are probably the result of earthquakes. Nearly all the lava flows are basalt, but the earliest seem to be andesite.
>
> The end of the flow of basalt from the present crater is exposed in a sea cliff on the northern shore of the island, and tells in some detail the story of the last eruption of Mount Iraya. The mountain had been quiescent for a period long enough before the eruption to allow a considerable stream valley to be cut through the bedded deposits of volcanic débris which form the cliffs of this neighborhood. The renewal of its activity was marked by considerable explosive force which probably blew away

part of the northern side of the present cone and nearly filled the valley with a mass of angular fragments of volcanic material. The latter part of this explosive phase was marked by the presence of a number of basaltic bombs. Finally, a stream of basalt several feet thick flowed down this valley, completely filling it. Since then the lava flow has itself been buried under the mass of loose material constantly creeping down the slopes of the mountain.

He mentions the appearance, in 1860, of a volcanic cone built up out of the sea in the region of the Didicas Rocks, and quotes Becker on its history:

In 1856 a new volcano made its appearance not far from Camiguin, at the Didicas volcano. It appeared in September or October, 1856, between two rocks well known to the natives, at first as a column of "smoke." No earthquake attended its first appearance, but in 1857 it underwent a violent eruption, attended by earthquakes. From that time to 1860, when Mr. Semper saw it, the volcano was constantly active, and in four years had reached a height, according to his triangulation, of 700 feet. He was unable to visit the spot.

We have no information as to how long the volcano remained in eruption after Semper's visit in 1860. Apparently, it was built up largely of loose materials and, at the time of Worcester's visit in 1907, had been largely, if not entirely, destroyed by wave action. Worcester's description, quoted by Ferguson, is as follows:

We found that this volcano, which rose from the sea in 1859, and gradually increased in size until it attained a height of 700 feet, had completely disappeared.

BABUYAN CLARO

Ferguson says:

Babuyan Island is about 13 kilometers in a northeast and southwest direction and has an average width of about 10 kilometers. At the western point is a volcano 670 meters high. This mountain is conical in shape and evidently contains a small crater at its summit. Flows of rough scoriaceous basalt surround the base and the mountain itself is built up of alternating basalt flows and deposits from explosive eruptions, angular basalt fragments, bomb lapilli and small slaglike masses. The writer had an opportunity to land here for a short time and, although unable to reach the summit, collected specimens of the basalt from one of the earlier flows and from the latest flow.

In the eastern part of the island is another volcano, 1,160 meters in height and heavily timbered. On its southern side were active fumaroles.

Several eruptions of the volcanoes of this island have been noted. Horsburgh in 1817 mentions a volcano on the western point, though he does not speak of any eruption having occurred. Fuchs mentions an eruption as having occurred in 1831. Becker quotes Meyen as mentioning this eruption, and Semper as stating that Babuyan Claro seemed then (1860) to be continually in eruption.

In 1919, during May, the captain of a merchant vessel plying between Manila and Batanes, reported a great eruption of the Babuyan Claro Volcano. The rough state of the sea prevented him from approaching the island.*

CAMIGUIN

Of Camiguin Volcano (north of Luzon), there is little to be said save that it is an extinct volcano of moderate height with some solfataras on the slope. Ferguson was unable, owing to illness at the time he landed on the island, to go very far up its slope or to make any study of it, and no other geologist, as far as is known, has been there. For Ferguson's remarks on this island see the chapter on Regional Geology.

This is the place where the Camiguin North Mining Company for a time mined sulphur for the local market.

MOUNT CAGUA (CAUA)

On the mainland of Luzon, in the eastern cordillera, almost due east of Aparri, are some fumaroles located on Cagua, a mountain of moderate elevation (1,197 meters); when Ferguson was there in 1907 there were only these fumaroles. It is relatively unimportant and the nearest approach to an active volcano in the whole of northern Luzon.

BULUSAN VOLCANO

In southeastern Luzon in Sorsogon Province is situated Bulusan Mountain, a dormant volcanic stock which was the scene of considerable activity in January, 1918. Goldsberry,(290) has written an account of this eruption, but we quote here from some notes by Saderra Masó,(424) who also visited the volcano at that time.

> Our attention was also turned during the last two years towards Bulusan volcano, which after having been dormant for centuries awakened in October, 1918. The previous year had seen some few very small explosive eruptions throwing out exclusively the old material filling the chimney, but in 1918 it began to pour pasty lava, which formed a current of rough and broken stones within the old large crater, and occasionally tumbled down a ravine, which seemingly had been opened through its southern wall as an outlet for the rain water collected in it. Such pourings of lava were very frequent: during the day they resembled black, steaming stones, detonating and breaking into gravel in their fall along the ravine; at night they appeared red hot and sparkling. At long intervals, a current of supposed more liquid lava rushed down the ravine; observed

* See Saderra Masó, Bull. Seis. Soc. Ann. 9 (1919) 37.

during the day it resembled a foaming and steaming current of grayish mud, which ended in a gray cloud of dust covering the ravine and its borders; the dust cloud darkened as it was rising, some streaks of it remaining high up among the cumulus clouds for many hours after each pouring. So far the results of the activity of this volcano have been falls of sandy ashes on the plantations and towns around the mountain with very little or no damage at all. Nevertheless to appease the people of the said towns, fearing greater impending eruptions, scientists of the Weather Bureau and of the Bureau of Science were sent to the place to examine the conditions. The first step was to place as near as possible to the volcano a sensitive seismograph in order to detect micro-seismic movements revealing residual interior strain. The instrument showed that there were no such movements, excepting the expected shock produced by each explosive eruption; consequently the opinion was that the volcano had only normal and easy discharges which could prevent accumulation of new great energy. Any impending great eruption was considered as not probable; in fact the occurrences of nearly two years of activity have proved the accuracy of such conclusion.

I question that any genuine lava eruption took place.

During the last five years two other, very little known volcanoes had explosive eruptions. The first, Ragang Volcano, is situated in central Mindanao. It belongs to the volcanic region of the widely reported Makaturing Volcano in Cotabato district.

MOUNT ARAYAT

Of all the older volcanic cones in the Philippines perhaps the most interesting, because of its situation, is Mount Arayat. This early Pleistocene or Pliocene volcano is situated near the center of the central plain in latitude 15° 13′ north and longitude 120° 42′ east, and rises to a height of 1,024 meters; it is made up of basaltic agglomerate on the surface. The mountain is densely wooded and no well-defined crater exists. This is the most conspicuous landmark in central Luzon. A large amount of tuff in the plain surrounding it undoubtedly had its origin here. Oebbeke has described the rock petrographically. I ascended the mountain on February 5, 1922. The best way up is from the Pampanga Farm School at its northwest base and near the town of Magalan.

CAMIGUIN VOLCANO (NORTH OF MINDANAO)

The following is from the bulletin by Saderra Masó:(401)

The small island of Camiguin lies near the north coast of Mindanao, between 9° 42′ and 9° 14′.7 north latitude and longitude 124° 39′.7 and 124° 47′.4 east of Greenwich. It consists of a single range of mountains,

apparently a prolongation of the central range of Mindanao, its northern extremity forks, forming the two ridges of Catarman and Mambajao. The island is Y-shaped, with the base lying southeast. Three principal peaks rise rather sharply, and are supposed to be extinct volcanoes. The whole island is famous for its great fertility, shown in the exuberant vegetation which covers even its steepest hillsides. Plantations of abaca are seen everywhere, even on the almost inaccessible slopes. Close to the foot of Mt. Catarman, to the west and near the seashore, rises the active volcano, which was in eruption from 1871, when it first broke forth, until the year 1876. Adhering, as it were, to the side of the mountain, and in a spot that was formerly an extensive depression, it rises to the height of 1,499 feet above the sea, with a base measuring more than 3,000 feet in diameter. This small volcano, known abroad as the Catarman volcano, is merely a recent mouth or crater of the gigantic and much older one that has been dormant for many centuries, but which now seems to be waking up.

Previous to 1871 no eruption has been recorded, but in that year earthquakes, increasing in intensity, finally culminated in a violent explosion at about 7 p. m. of April 30, which was succeeded by outpouring of gases and showers of mud and stones. Ashes from this explosion are said to have reached Cebu, 176 kilometers away.

Camiguin was visited by the Challenger Expedition in 1875, and at that time the volcano was still smoking and incandescent at the top. It is apparently completely extinct to-day.

BUD DAJO

Near the center of Jolo Island, in Sulu Sea, is a small, perfectly symmetrical ash cone of Recent age, now dormant or extinct, which is both very picturesque and famous historically. This well-preserved cone is densely wooded and has a fine crater at the top. The crater is about a half kilometer in diameter, and a stream of water flows out of it to the plain through a notch in the rim.

Discussion of many other interesting peaks and extinct craters, such as Banahao and Maquiling, the solfataras of Leyte and Biliran, and the beautiful little crater lakes of the San Pablo region, will be omitted from this chapter.

SUMMARY

The Philippines are a part of the Pacific volcanic belt, but there is less volcanic activity in the whole Archipelago than there is in one island of the Hawaiian group.

Taal Volcano has been the most destructive to human life.

Mayon Volcano is a nearly perfect cone.

There is no indication of lava flows around the recent vents. All the eruptions of recent times have been of the explosive type.

Andesite seems to be the principal rock found about the older stocks, while basalt seems dominant in the later outbursts.

Volcanism in the Philippines seems to be decidedly on the wane.

Hot springs, solfataras, and fumaroles abound from one end of the Archipelago to the other, and there are hundreds of square kilometers covered with andesite, basalt, and their tuffs, testifying to a period, not long since, of great volcanic activity throughout the Archipelago.

PALEONTOLOGY *

INTRODUCTION

The study of ancient life in the Philippines has great economic value in connection with the stratigraphy of sedimentary beds containing coal and oil, and with the associated strata. The relative geologic age of rocks in a given district may be determined by a study of the order of deposition, provided there have been no great disturbances such as faulting and intense folding; but such an ideal condition is seldom obtained. In the Philippines, in addition to the above-mentioned factors, a heavy cover of forest and high grass obscures the rocks, and the land masses are broken by deep seas. Partially to reassemble the shattered mosaic of the Past, one must study the "Books of Rock" and their fossil contents. In this way only can the geologic history be read and the patterns of Nature deciphered. At best, the evidence will be incomplete, but often after much labor a fairly complete outline of the design can be obtained.

For the benefit of the layman, it is necessary to state a few of the principles of paleontology, the study of ancient life. That the life of the Present was evolved from the Past is axiomatic in this study. Life through long geologic ages has been continuous, and on this account such a discontinuous record as is evidenced in the succession of different rocks in a given area can only be interpreted by reference to this unbroken life line and to the fossil record in far-distant regions. On account of this fossil record paleontologic advances depend upon world-wide investigations by many workers, and a certain familiarity with this great world field is necessary to arrive at broad conclusions. Such extensive studies indicate that, once a species is extinct, that particular life form is never repeated. This principle is particularly useful in picking out special fossils which indicate certain beds. These horizon determiners are almost invariably extinct forms, and the determination of the geologic

* This chapter is contributed by Roy E. Dickerson, honorary curator of the department of paleontology, California Academy of Sciences, San Francisco, and is reprinted, with slight alterations, from Philip. Journ. Sci. 20 (1922) 195–229.

time during which they lived can only be found after much collecting in many localities. In general, these extinct forms are the highly organized ones which have developed special adaptations particularly suited for their immediate environment. A slight change in climate, food, or salinity may be sufficient to cause such forms to become extinct or to develop other habits. New habits quickly, geologically speaking, cause specific changes and a new species results. The recognition of such evolutionary series of forms makes it possible for the paleontologist to recognize comparatively small divisions of geologic time, and its importance in oil and coal work is very great. In temperate latitudes these changes are marked, but my recent work indicates that in the Tropics, where climatic changes have been but slight, evolution has proceeded much more slowly. As was stated above, the highly organized species make the best horizon determiners, and one fossil like *Vicarya callosa* Jenkins is of more value in horizon determination than are several dozen others associated with this extinct but once widespread Asian species. Corals are highly specialized, and on this account they should prove to be particularly useful in the Philippines.

PREVIOUS WORK

Baron Richthofen(525) first reported some interesting Foraminifera from Binangonan Peninsula and referred to them as *Nummulites;* he assigned the beds that yielded them to the Eocene. Later, Abella(11) referred certain limestones in Cebu to the Eocene, as they likewise contained supposed *Nummulites.* Felix Karrer(349) described some Foraminifera from Zambales Mountains and recognized the Miocene age of the tuffs that yielded them. Martin, in a very excellent paper, laid the first firm foundation for Philippine paleontology by recognizing *Vicarya callosa* Jenkins and its associated fauna in Miocene beds of Cagayan Valley and the vicinity of Aringay, La Union. His recognition of Pliocene in Agusan Valley on apparently very scanty evidence really indicated his great grasp of Malaysian paleontology and geology. Warren D. Smith(555) reviewed the question of the age of the Binangonan limestone and showed that the foraminiferal limestone did not contain *Nummulites,* but did contain larger species which he described as *Orbitoides.* Douvillé(195) referred these forms to *Lepidocyclina.* Smith also recognized *Vicarya callosa* in the Batangas Peninsula and described several other forms associated with this guide fossil.

Later,(588) he described more new fossils from the Philippines and figured some characteristic species. In an economic report by Pratt and Smith, the latter(505) determined the species in the various horizons and figured the species collected from the beds. Two years ago H. Yabe,(659) of the Tohoku Imperial University of Japan, published a careful discussion of *Lepidocyclina* of the Philippines with excellent illustrations of several new species of this genus. The Vigo fauna and its bearing upon the rate of evolution of Mollusca in the Tropics has been recently discussed.(190)

As will be shown later in this paper, the fossil clams and snails occurring in the Tertiary enable us to correlate these beds with the oil-bearing horizons of Java and Sumatra. This correlation clearly indicates that there are possibilities of economic production of petroleum in the Philippines. In such a manner are broad geologic explorations guided by paleontology.

Many volumes of Earth's Books of Rock are missing in the stratigraphic record of the Philippines and, of the individual books, complete chapters are missing or so badly mutilated by subsequent earth movements—the geologic scribes—that their deciphering is extremely difficult. The Archean and Paleozoic sets are entirely missing. Of this great library of Earth's Geologic History, only a small fragment of the Mesozoic set is known, and even in the Tertiary only the Miocene and Pliocene prints are fairly readable. Much of the Pleistocene volume, the last of this wonderful History, is yet to be pieced together, although it is fresh from the Graver's hands. This is clearly set forth in the stratigraphic table facing page 66.

Warren D. Smith first recognized in certain cherts and slates in Ilocos Norte unicellular forms, Radiolaria, which appear to be of probable Jurassic, middle Mesozoic, age. Concerning these rocks Smith says:(558)

> In Ilocos Norte, Pangasinan, Balabac, Panay, and other localities there are outcrops of hard, red cherts or jaspers, in some places as hard, structureless bowlders and in others as fissile beds. When I first found these in Ilocos Norte, I compared them with the cherts of California. On examination with a microscope they were found to contain fragments of radiolarian tests. These rocks have a wide distribution in this part of the world, and have been provisionally assigned to the Jurassic by Martin.

In certain localities in Borneo rocks of proved upper Cretaceous age rest unconformably upon the older radiolarian beds, so it is clear that the upper possible limit, lower Cretaceous, is

fixed for these cherts. Hinde * compares the species of Radiolaria with radiolarian faunas elsewhere and concludes that their age is Jurassic.

Smith reports the same rocks from the western cordillera of Panay and from Bulacan Province, Luzon. He made slides from material collected by Dalburg at the latter place and recognized the Radiolaria *Cenosphaera affinis* Hinde and *Dictyomitra tenuis* Hinde. The photomicrographs given in Plate 5 illustrate these interesting marine forms. Similar forms have been described by Hinde in the appendix to Molengraaff's Explorations in Borneo.

The stratigraphic evidence of the relative age of these rocks in the Philippines is lacking, but the geographic distribution of similar rocks in the Moluccas and Borneo indicates that they all represent the same period. Unfortunately, the Radiolaria have a rather great geologic range, and on this account only a tentative assignment to the Jurassic is possible.

No Cretaceous rocks have been recognized in these Islands, although the Cretaceous is well developed in Japan.

TERTIARY

The lowest portion of the Tertiary, the Eocene—the dawn of modern life—has not been recognized with certainty in the Philippines, although rocks of this age occur in Japan to the north and Java to the south.

The genus *Nummulites* in many regions is characteristically Eocene, but in the East Indies this genus is not so restricted. The type locality of *Nummulites subniasi* Douvillé is in limestone associated with the coal measures of Batan Island. This form, according to Douvillé, is equal to *Nummulites variolaria* Brady from Nias Island which is located near the west coast of Sumatra. This species, according to Brady, is associated with *Nummulina ramondi, Orbitoides papyracca,* and *Orbitoides dispansa,* in Sumatra. The form identified by Brady as *Orbitoides papyracea* was later shown to be distinct from this species, and on this account was described under the name *Lepidocyclina verbeeki* by Newton and Holland.†

* Appendix on fossil Radiolaria of Central Borneo in G. N. F. Molengraaff, Geological Explorations in Central Borneo. Society for the Promotion of the Scientific Exploration of the Dutch Colonies. Leyden (1893–94).

† On some Tertiary Foraminifera from Borneo, Ann. & Mag. Nat. Hist. VII 7 (1901) 215.

Lepidocyclina verbeeki Newton and Holland occurs in the upper limestone above the coal in Cebu, a horizon of probable Miocene age. Thus it is that the general association and connections of *Nummulites subniasi* Douvillé are not with Eocene species but with Miocene.

Horizons of Oligocene age are not positively known. In certain localities Eocene and Oligocene times are represented by a line of unconformity between the basement complex of diorites and associated schists and the sedimentary rocks of Miocene age. In other words, a portion of the Philippines was a land mass during Eocene time, and on this account no marine sedimentary beds of Eocene age occur in certain regions.

MIOCENE

VIGO GROUP *

Rocks of Miocene age have been recognized in most of the larger islands of the Philippines and, owing to their widespread occurrence, this period of the Tertiary is best known. Since both oil and coal occur in these rocks their paleontology is of particular economic importance. The rocks of the Vigo group exhibit two pronounced faunal facies. The one occurs in limestone and is characterized by large unicellular forms (Foraminifera of the genus *"Lepidocyclina"*), whereas the other facies consists principally of clams and snails which lived in the sandy or muddy, moderately deep waters of an inland Miocene sea.

PELECYPODS AND GASTROPODS OF THE VIGO GROUP, SANDSTONE AND SHALE FACIES

The pelecypods and gastropods of the Miocene are best known from Bondoc Peninsula, Luzon Island. At many places in the southern half of this peninsula well-preserved fossils have been collected from the Canguinsa formation, the upper horizon of the Vigo, and from the underlying shales of this group. A partial list of these species is given in Table 24.

* I am not in agreement with Pratt and Smith concerning the stratigraphic relations of the Malumbang, Canguinsa, and Vigo in their type localities, Bondoc Peninsula. I believe that a great unconformity exists between the Malumbang and the underlying Vigo group. I failed to recognize an unconformity between the Canguinsa formation and the Vigo shale, although the areas cited by Pratt and Smith were critically examined. The relations that appear at these places are best explained by faulting. On this account the term "Vigo" is widened to include the Canguinsa formation as its upper sandstone facies, thus raising the term Vigo to a group rank.—R. E. D.

TABLE 24.—*Partial list of species from the Vigo group.*

GASTROPODA

Architectonica pictum Philippi.
Actaeon sp.
Cancellaria crenifera Sowerby.
Cancellaria elegans Sowerby.
Cassidaria.
Cerithidea cf. *ornata* Hinds.
Cerithidea (*Pyrazus*) cf. *sulcatus* Bruguiere.
Cerithidea near *dohrni* ?
Cerithium jenkinsi K. Martin.
Cerithium herklotsi K. Martin.
Cerithium moniliferum Kiener.
Cerithium bandongensis K. Martin.
Columbella bandongensis K. Martin.
Conus ornatissimus K. Martin.
Conus sp. nov. ?
Conus sp.
Conus lividus Hwass.
Conus loroisii Kiener.
Conus hardi K. Martin.
Conus striatellus Jenkins.
Cyclonassa elegans Kiener.
Cypraea cf. *tigris* Linnæus.
Cypraea sp.
Delphinula ?
Delphinula reeviana Hinds.
Distortio clathrata Lamarck.
Drillia sp.
Eburna ambulacrum Sowerby.
Ficus reticulata (Lamarck).
Haminea.
Harpa articularis Lamarck.
Mangelia.
Marginella.
Melania asperata Linnæus.
Mitra javana K. Martin.
Mitra cf. *jenkinsi* K. Martin.
Mitra junghuhni K. Martin.
Mitra buccinifórmis K. Martin.
Murex endivia Lamarck.
Nassa crenulata (Bruguiere).
Nassa dispar Adams.
Nassa gemmulata (Lamarck).
Nassa globosa minor Quoy.
Nassa thersites immersa Carpenter.
Nassa thersites leptospira (Bruguiere).
Nassa quadrasi Hidalgo.
Nassa canaliculata Lamarck.
Nassa costellifera A. Adams.
Nassa reussi K. Martin (may = *N. costellifera*).
Natica albumen Lamarck.
Natica ?
Natica spadicea Reeve.
Natica mamilla Lamarck.
Natica lacernula d'Orbigny.
Natica cumingiana Recluz.
Nerita funiculata Reeve.
Olivella.
Phos roseatus Hinds.
Ranella.
Ranella subgranosa Beck.
Ranella tuberculata Broderip.
Rostellaria fusus Linnæus.
Rostellaria crispata Kiener.
Strombus canarium (Linnæus).
Strombus sp. a.
Strombus sp. b.
Strombus swainsoni Reeve.
Strombus (?) sp.
Strombus (?) *fusus* K. Martin.
Telescopium telescopium Linnæus.
Terebra javana K. Martin.
Terebra bicincta K. Martin.
Terebra.
Thais (or *Ricinula*) spectrum.
Triton pfeifferianum Reeve.
Trochus.
Turris (*Surcula*) *flavidus* Lamarck.
Turris garnonsi Reeve.
Turris deshayesi (Doumet).
Turris carinata woodwardi K. Martin.
Turris coronifer (K. Martin).
Turris marmorata (Lamarck).
Vicarya callosa Jenkins.

TABLE 24.—*Partial list of species from the Vigo group*—Continued.

PELECYPODA

Arca cornea Reeve.
Arca ferruginea Reeve.
Arca granosa Linnæus.
Arca cf. *coelata* Reeve.
Arca tenebrica Reeve.
Barbatia fusca (Bruguiere).
Cardita antiquata Linnæus.
Cardium.
Cardium attenuatum Sowerby.
Cardium unicolor Sowerby.
Chione chlorotica Philippi.
Chione ?
Clementia hyalina Philippi = *C. papyracea*.
Corbula socialis K. Martin.
Dosinia cf. *lenticularis*.
Dosinia cretacea Philippi.
Glycimeris angulatus (Lamarck.)
Glycimeris viteus (Lamarck).
Ostrea sp.
Paphia textrix Deshayes.
Pecten (*Pleuronectia*) *pleuronecta* Linnæus.
Pecten cf. *radula* Linnæus.
Pecten cf. *pseudolima* Sowerby.
Pecten pseudolima Sowerby.
Pecten cf. *cristularis* Adams and Reeve.
Pinna sp.
Placuna placenta Linnæus.
Psammobia cf. *lessoni* Blainville.
Psammobia sp.
Solen sp.
Solecurtus quoyi Deshayes.
Spisula sp.
Spondylus sp.
Tellina sp.
Tellina sp.
Vermetus javanus ? K. Martin.

In the above list about 75 per cent of the specifically determined forms are living species, an astonishing percentage when the geologic history of the region yielding these forms is considered. The extinct forms are practically all common to the upper Miocene of Java according to K. Martin,* and they are practically all highly organized species. Such highly developed species are particularly fitted to their surroundings and a slight change in life conditions might cause the extinction of the species or bring about a specific change. As was noted above, the percentage of Recent species is remarkably high and, from a detailed study of the subject, I conclude that the evolution of marine molluscan faunas in the Tropics is far slower than in the Temperate Zones.† On this account the same "yardstick" in the Tertiary geologic time scale cannot be applied in both tropical and temperate regions. The scale used in the temperate zones is approximately as follows: Eocene, 0 per cent living species but practically all genera living; Oligocene, 3 per cent living species; Miocene, 25 per cent; Pliocene,

* Tertiarschichten auf Java. Leyden (1880) 44–51.

† Dr. Karl Martin some years ago called attention to the same thing in the case of the fossil marine fauna of Java.—W. D. S.

60 per cent; Pleistocene, 90 per cent. It is my opinion that this percentage scale in the Tropics must be considerably widened.

On this account the careful determination of guide fossils is of great economic importance. Good guide fossils are far more difficult to select in connection with tropical Tertiary faunas of the Philippines than in the California Tertiary, owing to the great predominance of Recent Mollusca. As will be seen from a study of the fauna cited above, most of the forms which are extinct were originally described from a correlative horizon in Java. Of these I am inclined to think that *Cerithium jenkinsi, C. herklotsi, C. bandongensis, Mitra javana, M. jenkinsi, M. junghuhni, M. buccinifórmis, Turris coronifer, Terebra bicincta, T. javana, Vicarya callosa,* and *Vermetus javanus* will probably prove reliable guides among the Mollusca. These species are all representatives of highly organized genera and their extinction during post-Miocene time was probably due to their inability to obtain life conditions suited to their highly specialized needs.

Corals, echinoderms, and the more highly organized Foraminifera will probably prove to be even better horizon determiners, but their comparative infrequence in strata of the Philippines will at times preclude their use. I have not yet attempted to identify the corals and the echinoderms in the collections made, but their value will no doubt prove to be great. It seems that their rate of evolution may have been greatly retarded, but much study will be required in this connection. For stratigraphic work in the Tropics large and complete collections are necessary to obtain results of much value, in as much as the geologic and paleontologic history, even with the best data available, is read with much difficulty. Much comparative material, both Recent and fossil, should be accumulated, as subspecific differences will be recognized only through comparative studies. These subspecific differences are exceedingly important for minute separation and discrimination of strata deposited under tropical conditions.

Some of the most abundant species and guide fossils for the sandstone and shale facies of the Vigo are illustrated in Plate 9.

LEPIDOCYCLINA LIMESTONE FACIES OF THE VIGO GROUP

The limestones of the Vigo group are characterized by the abundance of the large foraminifer *Lepidocyclina* associated with other Foraminifera. This limestone is in certain places stratigraphically associated with sandstones and shales which

have yielded a typical Vigo fauna. The best region for the study of this facies is in Cebu Island, where the limestone which overlies the coal at Danao has yielded several species of these interesting and important unicellular animals. According to Douvillé(195) these beds represent the middle horizon.* Douvillé states that the study of Foraminifera permits him to make the following subdivisions:

I. The lower lignitic horizon is characterized by the association of the genera *Nummulites* and *Lepidocyclina*.

II. The middle horizon is characterized by the abundance of *Lepidocyclina* and the presence of *Alveolina*.

III. The upper horizon has an abundance of small *Lepidocyclina* and *Miogypsina*. Douvillé states that this same succession occurs in Borneo and Indo-Asia. He correlates the lower horizon with the Stampian, Oligocene; the middle, with the Aquitanian, lower Miocene; the upper, with the Burdigalian, Miocene. In a footnote Douvillé states that in conformity with recent work, the limit between the Oligocene and the Miocene, or between the Eogene and the Neocene, is placed between the Stampian and the Aquitanian, properly limited. Douvillé's conclusions are as follows:

From the preceding study the writer is enabled to classify the described beds in the following manner:

I. Eogene (comprising the Eocene and the Oligocene), Stampian Stage.

Limestone of Caracaran (Island of Batan, locality 2).

This is a bluish gray limestone upon which the Foraminifera stand out in black; it is a part of the lignitic horizon and is intercalated between beds of lignite.

The thin plates and polished sections show a small species of *Nummulites*, 2.7 millimeters in diameter, which appears to correspond to *N. niasi* Verbeek; but the latter species is microspheric while that of the Philippines is macrospheric, and has been distinguished as *N. subniasi*. This same limestone also yields *Polystomella* sp. and a curious *Lepidocyclina* belonging in the section *Neophrolepidina, L. smithi*, which resembles certain varieties of *L. proemarginata*.

The coëxistence of *Nummulites* and *Lepidocyclina* characterizes the Stampian; it is noteworthy that these two genera are not represented here except by forms of very small size, although a little farther south, in Borneo, the large forms are abundant.

II. Neocene (Aquitanian, Burdigalian, Helvetian), Aquitanian Stage.

1st. The soft yellowish sandstone of Sibul Gulch (old Alpaco Mine, Island of Cebu, locality 273). The sandstone is incoherent and but slightly cemented by limestone. The fossils are casts and the internal characters are difficult to recognize. The fauna is essentially composed of *Orbitolites*

* Douvillé's studies were not made in the Philippines, but upon material collected by W. D. Smith.

and *Alveolinella*, with *Operculina costata* var. *tuberculata*, *Rotalia*, *Polystomella*. This bed is indicated as above the coal and below the *Lepidocyclina* limestone. This ought to correspond nearly to the horizon with *Orbitolites* and *Alveolinella* in Java which Mr. Verbeek places as stage m, that is to say, in the lower Aquitanian. Owing to the poor state of preservation of the fossils, this reference is only a provisional one. It is to be noted that Professor Martin announced the discovery by Semper of *Orbitoides* in a mine of Alpaco.

2d. The best-characterized horizon is the limestone with the large lepidocyclinas:

Limestone of Guila-Guila (Cebu, locality 278). There occur numerous lepidocyclinas of large size; some present surfaces having well-developed turbercles, and these have been referred to *Lepidocyclina insulae-natalis;* the others, with but few if any tubercles, have been assigned to *Lepidocyclina richthofeni*. These two forms are very numerous; they are associated with a third species, a much smaller form, composed of a central part, very swollen, bordered by a collarette; this is *L. formosa*, nearly free from tubercles, but it presents very thick walls between the chamberlets. These various forms are often found free.

There are places representing this same horizon, the limestones of the Barrio of Mesaba (Cebu, locality 272) *L. insulae-natalis;* those of the valley of Cumajumayan (Cebu, locality 28) *L. richthofeni* and *L. formosa;* the two latter forms occur together with a third species, *L. inermis*, which has thin walls between its cells, at Compostela Mine (Cebu, locality 289).

3d. There is another horizon probably to be placed slightly higher, a soft limestone bed, cream white in color, which outcrops boldly in great escarpments along the road from Toledo to Cebu, on the edge of the Minanga River (locality 277, near Camp 1); this presents upon its surface very well-preserved specimens of *Operculina complanata* and *Cycloclypeus communis*. This bed is correlated with the Silex marls of the Aquitanian of Borneo.

III. Burdigalian Stage.

This upper horizon is characterized by the appearance of *Miogypsina* and by the abundance of small lepidocyclinas of the section *L.* (*Nephrolepidina*) *verbeeki*. I refer the two following beds to the Burdigalian:

A very soft, sandy, yellowish limestone of Gaba Bay, Batan Island (locality 8), above the lignitic beds; there occur well-preserved but fragile forms, among which are *Globigerina*, *Cycloclypeus communis*, *Amphistegina* cf. *mamillata*, and a small *Miogypsina*, the last being referred to a Burdigalian form occurring near Dax (France).

A very soft white limestone which runs along the cordillera central of Cebu Island, Valley of Cotabato (locality 279); here occurs *L. verbeeki*, which was first described by Mr. Warren D. Smith, but above all it is associated with *L. inflata* and numerous *Miogypsina irregularis*.

Of these three faunas which I recognized, the second is characterized principally by the great abundance of large *Lepidocyclina* which has a very great distribution from Madagascar to the Philippines. I recognized in my study upon the Foraminifera of the Tertiary of Borneo that they correspond to the Aquitanian; I have distinguished three horizons, E, F, G, which it ought to be possible to find in the Philippines when geological explorations are more advanced.

The upper horizon Burdigalian H (of Borneo) also presents a very great distribution; it is well developed in the island of Nias, near Java, from whence comes the type of *L. verbeeki* and from Borneo where I have not been able to distinguish this species from the similar European form *L. tournoueri*. This same horizon appears to extend to the north in Formosa and Japan in the environment of Tokyo. This last locality is in latitude 36°, that is to say, near that of Gibraltar; however, the *Lepidocyclina* occur in France nearly to latitude 44° and beyond 45° in Italy.

The following table summarizes the references which I recognize:

	Philippines.		Borneo	
II.	Upper limestones with small lepidocyclinas	*Lepidocyclina verbeeki* *Miogypsina* *Cycloclypeus communis*	H. Burdigalian.	
	Middle limestone	*Cycloclypeus communis* *Operculina complanata*	G.	Aquitanian.
	Lower limestones with large lepidocyclinas	*Lepidocyclina insulae-natalis* *Lepidocyclina richthofeni* *Lepidocyclina formosa*	F. E.	
I.	Lignitic horizon and lower limestones with nummulites	*Nummulites subnias* *Amphistegina niasi* *Lepidocyclina smithi*	D. Stampian.	

In Europe the succession of faunas is very analogous; the lepidocyclinas are well developed, moreover, likewise in Spain, as well as Italy, where they attain a great size and are associated as in Borneo with reticulated *Nummulites*. The section of which *Lepidocyclina dilatata* is an example corresponds to the Asiatic section of *L. insulae-natalis* and extends into the Aquitanian. Moreover, in the upper beds the section of *L. tournoueri* is represented by that of *L. verbeeki*. With these two are associated, moreover, *Miogypsina*.

The European basin and the Asiatic basin appear to have been completely separated at the end of the Eocene by the uplift of Lybia which was developed across the Mésogée and separated the Mediterranean from the Indian Ocean. It is only during very recent time that the Red Sea has almost reëstablished a communication between the two seas, but the waters of the Indian Ocean are even now several kilometers separated from the Mediterranean by the slight barrier of the Isthmus of Suez.

The limestones referred by Douvillé to the Stampian occur, as stated by him, between coal seams in Batan Island. At this locality or in its near vicinity in the gray shale overlying the East Batan coal seam in the Perseverancia claim very excellent specimens of *Vicarya callosa* Jenkins and numerous species of *Corbula* were obtained by F. A. Dalburg (Bureau of Science locality No. 7). *Vicarya callosa* Jenkins is regarded by Martin

and other workers as being one of the best horizon markers of middle and upper Miocene in the East Indian islands. In this connection Smith states that—

> this species is moderately common in the Philippine coal measure shales, being especially plentiful in the shale above the principal coal seam on the east end of Batan Island, Albay Province. It is also found in the same position in the coal measures in Cebu and Mindanao.

On this account it seems to me that the above reference to the Oligocene is very questionable, and it is my opinion that this Batan coal is of essentially the same age as is the coal of Cebu and of tunnel 14 of Sibuguey Peninsula, Mindanao. At the latter place, Dalburg collected splendid specimens of *Vicarya callosa* Jenkins from the coal seams and shales (Plate 9, fig. 1). *Vicarya callosa* is associated with the coal seams of Cebu and seems to be a form which flourished in brackish water. Whether or not this form is very limited in geologic range is probably open to question, as those forms which have a great geographic distribution frequently have a considerable stratigraphic range as well. It is probably limited to the Vigo group at least; that is, to about 1,000 meters of sedimentary beds, as it never has been reported from the Malumbang formation.

Douvillé places locality 272 in his II, 2, the *Lepidocyclina* limestone. The Bureau of Science possesses an excellent collection of gastropods and pelecypods from this place collected by Smith, among which the following forms have been identified:

Locality F272 (Cebu)

GASTROPODA

Bullaria ampulla (Linnæus).
Conus sp.
Cerithium (*Campanile*) sp.
Cerithium sp.
Cerithium jenkinsi K. Martin.
Cerithium herklotsi K. Martin.
Cypraea sp.
Fusinus sp.
Natica sp.
Turbinella junghuhni K. Martin.
Trochus sp.
Turbo sp. a.
Seraphs sp.
Vicarya callosa Jenkins.
Voluta innexa Reeve.

PELECYPODA

Chione lacerata Hanley.
Lucina sp.
Pecten cf. *lentiginosus* Reeve.
Pecten leopardus Reeve.
Plicatula imbricata Menke.

A brief comparison of these forms with collections from the Vigo group of Bondoc Peninsula clearly demonstrates essential faunal unity.

Smith reported some of the large Foraminifera from Bondoc Peninsula from beds of Canguinsa age. He says:

> The limestone from Mount Morabi contains *Cycloclypeus communis* K. Martin which represents the middle Miocene, and large lepidocyclinas, some of which are 45 millimeters in diameter and 5 millimeters in the thickened central portion. * * * This species has been referred by Douvillé to the lower Miocene.

This *Lepidocyclina* fauna occurs in the upper portion of the Vigo group, the Canguinsa formation. This formation in the same region has yielded a large part of the mollusks reported above, and it is clear that the vertical range of the large representatives of the genus *Lepidocyclina* is much greater than Douvillé suspected.

H. Yabe,* in a recent publication, recognizes this possibility and he reviews the case as follows:

> L. Rutten studied foraminiferal rocks from southern and eastern parts of Borneo and found it necessary to modify somewhat H. Douvillé's correlation of the Tertiary rocks, because *Lepidocyclina* appeared to him to have a more extended vertical range than was believed by Douvillé. Thus, the oldest Miocene and Oligocene deposits, according to Rutten are characterized by Lepidocyclinas of larger and smaller sizes, while the smaller ones alone are found together with Miogypsina in all parts of Miocene deposits except the lowest division.

Rutten † presents a table in his paper which is copied by Yabe. Yabe,(659) in another and later paper upon the *Lepidocyclina* limestone from Cebu, recognized *Lepidocyclina* (*Nephrolepidina*) *angulosa* Provale associated with *Lepidocyclina monstrosa* Yabe, *Lepidocyclina formosa* Schlumberger, and several other Foraminifera. It is evident from this assemblage that the section *Nephrolepidina* is not restricted to the uppermost horizon, as Douvillé thought.

Briefly, in conclusion, then, the *Lepidocyclina* limestone is equivalent to the shales and sandstones of the Vigo group and the molluscan faunas of the latter beds are equivalent to the large-sized *Lepidocyclina* fauna of Cebu. In other words, the limestones, shale, sandstones, and coal are different depositional facies within the same group, the Vigo of probable middle and upper Miocene age.

* Notes on a Carpenteria limestone from British North Borneo, Science Reports of the Tohoku Imperial Univ. II 5 [1] (1918) 2.

† Studien über Foraminiferen aus Ostasien, Samml. d. Geol. Reichmuseums I 9 (1911–1914) 287.

The corals of the Vigo group are not well known and many forms await careful description. In general, the corals of this group are either individual or slender, branching forms, and this characteristic is in great contrast with the coral fauna of the overlying Malumbang formation where the dominant forms are the large reef-building types with many large heads.

Smith(555) reports *Pattalophyllia* (?) *bonita* Smith, *Pachyseris cristata* K. Martin, and *Madrepora duncani* Reuss (?) from Bureau of Science locality 272, Barrio Mesaba, near Danao, Cebu, where they are associated with the large forms of *Lepidocyclina* and the Mollusca listed above from this same locality. *Pachyseris cristata* and *Madrepora duncani* are reported by Martin from locality P, where they are associated with *Vicarya callosa* and its characteristic molluscan associates.

FAUNA OF THE MALUMBANG FORMATION

Like the Vigo group, this formation of probable Pliocene age is very widespread throughout the Philippine Archipelago. Both lithologically and faunally this formation is in sharp contrast with the Vigo described above. The Malumbang corals, for example, are nearly all reef builders, colonial forms, while the Vigo corals are chiefly simple individual or slender branching forms. In the case of the Malumbang, these large colonial forms make the coralline limestone which is characteristic of this formation at its type locality, the Malumbang plain and Banaba Ridge vicinity in the southern end of Bondoc Peninsula, Tayabas Province, Luzon. Since this formation is best known at its type locality, most of the present discussion is based upon material secured from that region. Pratt and Smith(505) discuss the Malumbang fauna (Plate 10) at the type locality of the formation and give lists of species which I have slightly modified. They state conditions as follows:

> All three horizons in the Malumbang series are fossiliferous. Fossils were collected at two places on the hills at the northern edge of Malumbang Plain, which are capped by the Upper limestone. Specimens from fossil locality 61 were obtained on the hills north of Mount Anuing near the eastern rim of Canguinsa River valley at Bacau, and others (fossil locality 63) were found on the hills immediately to the east on the northern border on Malumbang Plain. The Upper limestone in this vicinity is sandy, and grades imperceptibly into the Cudiapi sandstone below it. The fossils are embedded in sandy, calcareous material which might be designated either as sandstone or limestone.

Fossils collected at locality 61.

Pecten senatorius Gmelin. +
Pecten leopardus (?) Reeve. +
Cytherea sp.
Cardium sp.
Schizaster subrhomboidalis Herklots.
Xenophora dunkeri K. Martin (?)
Turbo sp.
Conus sp.
Pecten senatorius Gmelin. +
Mitra sp.
Xenophora sp.
Spondylus imperialis Chem. +
Operculina costata d'Orb. +
Conus sp.
Olivia indet.
Strombus labiosus Gray. +
Melania sp.
Dosinia sp.
Lagenum multiforme K. Martin var. *tayabum* Smith.
Turbo sp.
Trochus sp.
Bulla ampulla Linn. +
Olivia sp.
Pattalophyllia sp. +

Of the determinable fossils in these and the following lists, those which represent living species are indicated by a plus sign.

Fossils were obtained from the Cudiapi sandstone at three different places, as follows: (1) Fossil locality 65, calcareous sandstone immediately beneath the Upper limestone in the hills north of Malumbang Plain, adjacent to fossil locality 61; (2) fossil locality 4, calcareous sandstone beneath the Upper limestone about 450 meters south of Balinsog Hill, at an elevation of 360 meters; (3) fossil locality 13, sandstone, at an elevation of 270 meters on the high ground between Apad and Milipilijuan Creeks, affluents of the Bahay River. The Upper limestone does not occur over the sandstone at this place, but the sandstone itself is very calcareous.

The fossils from the Cudiapi sandstone were determined as follows:

From fossil locality 65.

Pecten sp.
Schizaster subrhomboidalis Herklots.
Dosinia sp.

From fossil locality 4.

Turbo sp.
Nassa sp.
Fusus sp.
Pleurotoma sp.
Melania sp.

From fossil locality 13.

Clementia sp.
Xenophora dunkeri K. Martin.
Ostrea orientalis Chemnitz. (?) +
Pecten senatorius Gmelin. +
Cerithium herklotsi K. Martin.
Pleurotoma tjomoroënsis K. Martin.
Pleurotoma carinata Gray. +

Fossils from limestone at a horizon corresponding stratigraphically with that of the Lower limestone were collected at three localities, namely: Fossil locality 44, at the mouth of Ayoni River; fossil locality 59, on a prominent hill (elevation, 250 meters) 2 kilometers west of Tala; and fossil locality 25, near Tambo, a barrio of San Narciso. However, as

will appear in the discussion of the field relations at these localities, only the last group in the foregoing list represents certainly the Lower limestone; the fossils from the other localities may belong to either the Upper or the Lower limestone.

On the north side of Ayoni (Yuni) River near its mouth, fossils were found in the limestone which forms the ridge along the Western coast of the peninsula.

Fossils collected at locality 44.

Cypraea sp.
Arca nodosa K. Martin. (?)
Schizaster sp.
Cerithum sp., large internal cast.

Along the western coast from Ayoni (Yuni) north to Catanauan, this limestone is found in the coastal ridge and occurs conformably only a short distance above beds which clearly belong to the Vigo shale. A short distance inland from Ayoni similar limestone occurs above the Canguinsa sandstone, and is overlain at places by the Cudiapi sandstone. This relation suggests that the limestone at Ayoni is the Lower limestone, but the evidence is not conclusive and either limestone horizon may be represented by the fossils from this locality.

Fossils collected at locality 59.

Pyrula gigas K. Martin.
Balanus sp.
Pecten leopardus K. Martin.

The limestone in which these fossils were found occurs on the top of a hill; below the limestone, with a concealed interval between, the Canguinsa sandstone was observed. The thickness of the concealed beds is hardly great enough to include the Cudiapi sandstone and the Lower limestone in their usual thickness. The fossils, therefore, are assigned to the Lower limestone, although they may represent the Upper limestone instead.

A sample of limestone (fossil locality 25), which certainly came from the Lower limestone horizon, was collected near the Cabongahan-San Narciso trail at an elevation of 180 meters, on the east side of the ridge extending northwest from Mount Cambagaco. Thin sections of this rock show small fragments of limestone and the well-known alga, *Lithothamnion ramosissimum* Reuss (Plate 8), intermingled in a cement of calcite.

The molluscan fauna of this formation is very sparse when compared with that of the Vigo group. This is in part due to poor preservation (as the surface waters readily penetrate the coralline limetones, marls, and sandstones) and in part due to original life conditions of deposition. The molluscan fauna living on coral reefs in these islands to-day is not characterized by a great variety of forms and, since much of the sediment of the Malumbang was laid down as Pliocene coral reefs, the molluscan assemblages found in these coralline limestones or their derivative marls consist of relatively few species.

State of preservation is no guide at all in determining the age of faunas in the Philippines. Vigo forms are often as well preserved as is beach material, while the much younger Malumbang

fossils are frequently badly decomposed. Even Pleistocene species secured from raised coralline limestone beaches are much older in appearance than Vigo forms. On this account, the field man should be especially careful not to permit state of preservation to influence his judgment in determining the relative age of any stratum he may study.

The best collecting locality yet found in the Malumbang was discovered by Mr. E. W. McDaniel who assisted me in making a good collection here. This locality is described as follows:

Locality 1x, Philippine Islands, Luzon, Tayabas Province, Bondoc Peninsula, west side of Ragay Gulf, 2.75 kilometers northwest of Bureau of Lands bench mark No. 1, in coarse sandstone (coral and shell sand) dipping 12° south, strike north 50° west. Collectors, E. W. McDaniel and Roy E. Dickerson.

The following species have been identified from this locality. The species living in these seas to-day are marked by L.

Partial list of species from locality 1x.

Fungia sp.
Schizaster subrhomboidalis Herklots.
Lagenum sp.
Clypeaster sp.
Arca ferruginea Reeve. L.
Arca cornea Reeve. L.
Arca sp.
Aspergillum annulosum Deshayes. L.
Cardium sp.
Cardita antiquata Linnæus. L.
Dosinia variegata Reeve. L.
Glycimeris sp.
Limopsis multistriata Forsk. L.
Modiolus sp.
Mytilus sp.
Macoma sp.
Metis sp.
Ostrea hyotis Linnæus. L.
Pecten leopardus Reeve. L.
Pecten senatorius Gmelin. L.
Pecten sp.
Placuna placenta Linnæus. L.
Pinna sp.
Spondylus imperialis Chemnitz. L.
Tellina sp. a.
Tellina sp. b.
Conus ornatissimus (variety) K. Martin.
Dolium costatum Menke. L.
Natica sp.
Turbo sp.
Turritella sp.
Leucozia unidentata de Haan. L.

The high percentage of Recent species is noteworthy and is in accord with my general conclusions based upon a study of the Vigo fauna.

The corals from the Malumbang formation have not received the careful attention that they deserve, and undoubtedly many important conclusions will be derived from their study. Students of the coral-reef problem may here obtain much material for study, as both Pleistocene and Recent coral reefs occur in the Archipelago as well as in these older beds.

Father Francisco de P. Sanchez, S. J., of Ateneo de Manila, recently loaned to the Bureau of Science his collection of fossil corals obtained from the coralline limestones near Mount Mirador Observatory at Baguio, Benguet Province. From a cursory study of this collection it is apparent that several of the species are identical with the reef corals collected from the Malumbang Pliocene at its type locality in the Bondoc Peninsula.

Concerning the coralline limestones of this general region, von Drasche * says:

> There can be no doubt that the coralline limestones belong to the most recent rocks occurring in northern Luzon. They always form the uppermost member of all formations, and with the exception of Benguet, where they are covered with a thin layer of red earth, I failed to find these limestones beneath other rocks. As has been said, they contain a number of coral fragments which, unfortunately, are in a poor state of preservation; they contain, although only in limited numbers, remains of lamellibranchs, gastropods, echinoderms, etc. All of these fossils have, however, suffered very much on account of the crystallization of the limestone.
>
> A more extensive examination of the same material undertaken by me in conjunction with my honored friend Doctor von Marenzeller, in charge of the collection of the Zoölogical Court Cabinet, led also to substantially the same results.
>
> Even though it was impossible to give a reliable specific report on account of the poor state of preservation of the fossils, it nevertheless was possible for us to declare with certainty that, with the exception of one single piece, which we could not identify, all of the rest belonged to genera which occur to-day in great abundance in the Indian Ocean, and even the individual corals can be referred without any question to living types. The corals examined do not show the least relationship to the Tertiary corals from Java described by Reuss.
>
> Regarded from this point of view, the raised coral reefs of Luzon must be considered as very recent in origin.
>
> The genera identified by us are the following: *Galaxaea* sp., ***Favia*** sp., *Maeandrina* sp., *Porites* 2 sp., (?) *Astraeopora* sp.

The stratigraphic as well as the paleontologic results go to show that the raised coral reefs of Luzon belong to the most recent geologic formation.

Stratigraphic confirmation of the paleontologic correlation of the Mount Mirador limestone with the Malumbang formation was recently obtained by Mr. H. P. Whitmarsh, who collected excellent specimens of *Vicarya callosa* Jenkins, a species characteristic of the Vigo group of Miocene age, from sandstones,

* Copied from King's translation of von Drasche's Fragmente zu einer Geologie der Insel Luzon. Wien (1878) 36–46. See Smith's Notes on a geologic reconnaissance of Mountain Province, Luzon, P. I., Philip. Journ. Sci. § A 10 (1915) 185–186.

lignites, shales, and shaly limestones which dip at an angle of 35° beneath the coralline limestone of Mount Mirador belt. This locality is about 6 kilometers west of Baguio and about 450 meters south of the Naguilian Road, which runs west from Baguio, elevation about 1,050 meters. An unconformity probably exists near this locality.

As von Drasche pointed out, the great altitude of this coralline limestone is very striking, and the great amount of movement in northern Luzon since these Pliocene coralline limestones were deposited is very notable. Mount Mirador is about 1,200 meters in elevation and similar limestones are reported from Sagada at 1,372 meters. Smith(592) describes the limestone at Sagada as follows:

> The most extensive development of it is probably at Sagada, where we find it projecting from the soil and talus in great masses as shown in the photograph. The bedding planes, which can be distinctly made out even in the picture, dip about 20° southeast. On the weathered surfaces the stone is bluish gray, but on fresh fracture it is cream white to reddish. The photograph shows the characterstic spirelike forms produced by the dissolving action of the heavy rainfall of this region.
>
> A thin section of the rock shows innumerable fragments of the well-known Mio-Pliocene marine alga, *Lithothamnion ramosissimum* Reuss (Plate 8). This formation, therefore, is equivalent to the upper limestone in Cebu and many other parts of the Archipelago.

Apparently associated with these coralline limestones are some fine-grained tuffs which yielded a fine flora. Smith's description of the locality is as follows:

> At Sagada, where Father Staunton, of the Sagada Mission, has opened a quarry to secure material for his new church, is perhaps the best section of the tuff beds to be seen anywhere in the province. The face of the quarry is about 15 meters high and reveals the following beds:
>
> 1. Soil and loose material.
> 2. Tuff in heavy beds, 1.5 to 3 meters.
> 3. Yellow-stained shale, 0.5 meter.
> 4. Tuff in solid bed with varying texture, 18 meters.
> 5. Bluish black shaly-looking rock which is very fine grained, 1 meter.
>
> * * * The dip is about 20° to the southeast. In the shaly portions are great numbers of leaf impressions.

Smith submitted these fossils to Mr. Elmer D. Merrill, director and botanist of the Bureau of Science, who described them as follows:

> The fossil remains, mostly remarkably clear leaf impressions, all, or nearly all, represent species still living in the Philippines at low and medium altitudes, and an examination of the material shows that the forest in the Bontoc locality was a typical mixed dipterocarp forest such as is

persists, from sea level to an altitude of about 800 meters. None of the species is found to-day within the limits of Bontoc subprovince, and very few of them are to be found in any part of Mountain Province. None of them is found above an altitude of approximately 800 meters, while the present altitude of the fossil-bearing strata is 1,500 meters.

Merrill identified the following living forms, some of which are shown on Plate 12:

Dipterocarpaceæ: *Shorea polysperma, Shorea guiso, Shorea* sp., *Anisoptera thurifera.*
Lauraceæ: *Beilschmiedia cairocan, Phoebe sterculioides.*
Guttiferæ: *Calophyllum blancoi.*
Tiliaceæ: *Diplodiscus paniculatus.*
Menispermaceæ: *Anamirta cocculus.*
Cyperaceæ: *Mapania humilis.*

As Merrill points out, great elevations have taken place here since this tropical, low-altitude flora flourished on the present site of Sagada. These tuffs and their associated coralline limestones are probably equivalent to the Malumbang Pliocene. Apparently plants of the tropical regions have changed but little since the Pliocene, thus again evidencing the slowness of evolutionary change in these climes.

UPPER PLIOCENE

BANISILAN FORMATION

The following species were collected from the Banisilan formation by Graham B. Moody at his locality 424 which he described as being 1 mile east of Matinao, ⅜ mile west of Malitabug River, Cotabato, Mindanao.

List of species from Moody's locality 424.

GASTROPODA

Calliostoma sp.
Cancellaria oblonga Sowerby.
Capulus sp.
Cerithidea sp.
Conus sp., large.
Conus lividus Hwass.
Conus insculptus Kiener.
Cypraea erosa Linnæus.
Cypraea sp.
Distortio clathrata Lamarck.
Dolium sp.
Eulima sp.
Murex cf. *pliciferas* Sowerby.
Nassa crenulata Bruguiere.
Nassa sp.
Natica albumen Lamarck.
Natica mamilla Lamarck.
Natica spadicea Reeve.
Pustularia nucleus Linnaeus.
Ranella subgranosa Beck.
Ranella sp.
Sigaretus eximius Reeve.
Triton clavator Lamarck.
Turris flavidula Lamarck var. *sonde* K. Martin.
Terebra sp.

PELECYPODA

Arca cf. *barbata* Linnæus.
Arca cornea Reeve.
Cardita antiquata Linnæus.
Cardita pica Reeve.
Chama sp.
Cardium unicolor Sowerby.
Chione sp.
Corbula sp.
Glycimeris angulatus Lamarck.
Leiconcha trimaculata (Desh.).
Lima sp.
Lucina sp.
Macoma nobilis Hanley.
Ostrea sp. a.
Ostrea sp. b.
Pecten squamosa Gmelin.
Pecten sp.
Spondylus sp.

COELENTERATA, ETC.

Echinoid spine.
Flabellum cf. *australe* Moseley.
Balanophyllia sp.
Cycloseris sp.
Three other coralline forms.
Vermes sp.

All the forms specifically identified are Recent species. The two forms *Flabellum* cf. *australe* Moseley and *Balanophyllia* also occur in Moody's locality 314, Humayan River, between Waloe and Loreto, Agusan Valley, Agusan Province, where they are associated with the following:

Cassis sp.
Cyclonossa elegans Kiener.
Nassa globosa Quoy.
Nassa crenulata Lamarck.
Nassa canaliculata Lamarck.
Cerithium jonkeri K. Martin.
Turritella terebra Lamarck.
Turris carinata Gray.
Arca ferruginea Reeve.
Paphia striata Chemnitz.

The form *Flabellum* cf. *australe* Moseley is identical with the species listed by Warren D. Smith from near Aroroy, on the west side of Aroroy Bay, Masbate, Bureau of Science locality F907, where it has a similar association as indicated above. The *Ballanophyllia* may be an extinct species, and I regard the association of these forms with similar assemblages of Gastropoda and Pelecypoda as not merely adventitious but indicative of essential synchrony. In other words, the Banisilan formation is equivalent to the beds exposed at Aroroy and the nearly horizontal beds at Moody's locality 314 in Agusan Valley. The latter are probably equivalent to beds referred to the Pliocene by Martin. Martin * listed Mindanao fossils as follows:

1. Left bank of Agusan River at Tagasáp.

Latirus madiunensis Mart. P.
Murex microphyllus Lam. M; L.
Ranella raninoides Mart. M.
Ranella gyrina Linn. L.
Turritella terebra Lam. Q; L.

[*] Martin, K., Concerning Tertiary fossils in the Philippines, English translation, Annual Rep. U. S. Geol. Survey 21 [s] (1899–1900) 619, 622, 623.

2. Agusan River between Pagasap and Libuton.

Turritella terebra Lam. Q; L. *Venus squamosa* Lam. P; L.

3. Maasin on the Agusan.

Conus insculptus Kien. M; L. *Murex verbeeki* Mart. P.
Turricula bataviana Mart. P. *Natica mamilla* Lam. M; L.

4. Salac y Maputi River.

Murex verbeeki Mart. P. *Clementia papyracea* Gray. M; P; L.
Strombus isabella Lam. Q; L. *Natica mamilla* Lam. M; L.
Arca granosa Linn. P; L. *Corbula scaphoides* Hinds. M; P; L.

5. Zamboanga, River bank 2.5 miles north of Zamboanga, upper stratum.
Murex capucinus Lam. L.

Concerning these species, he states his opinion, on pages 622 and 623, as follows:

As for Mindanao, it can not be demonstrated from specimens which have been investigated that Miocene strata occur there, for I have but a single species, *Ranella raninoides* Mart., which is known only in the Miocene. On the other hand, it is clear that there are upper Tertiary beds along the Agusan River. If it were permissible to assume that all the fossils of the list given above originated in equivalent beds, and their state of preservation makes this probable, there would be in all 10 species, 6 of them, or 60 per cent, still living; 4 species occur in the Miocene and the same number in the Pliocene; but of these last three are known only from the Pliocene. These are *Latirus madianensis* Mart., *Turricula bataviana* Mart., and *Murex verbeeki* Mart. All this argues the occurrence of the Pliocene on the Agusan River, and in harmony with this indication is the exceedingly fresh appearance of the fossils at hand.

The same age finally may be ascribed to the fossils from the river Salac y Maputi in Mindanao; for although of the 6 species determined from this locality no fewer than 5 belong to the present fauna, yet of these latter 4 reach back to the Miocene and Pliocene and a single species, *Murex verbeeki* Mart., is known only in the Pliocene. Of the deposit at Zamboanga nothing definite can be said as yet on the strength of the solitary fossil *Murex capucinus* Lam.

To the age determinations of Philippine fossils it is proper to add that their state of preservation resembles that of the Javanese fossils to a very remarkable extent—to such a degree, indeed, that the specimens from the two regions might easily be confounded. The same statement is true of the tuffs and marls in which they were embedded, and this accords with the fact that the younger massive rocks of the Philippines show an extraordinary likeness to those of the East Indian Archipelago.

I am in entire agreement with Martin's assignment of the Agusan beds to the Pliocene and their analogue, the Banisilan formation, as well. The descriptions of Moody and Smith of the stratigraphic relations of the tuffaceous sandstones at Banisilan yielding the above fauna to the conformably underlying

coralline limestone indicate that the Banisilan is upper Pliocene, since the coralline limestone is largely composed of corals characteristic of the Malumbang formation of Pliocene age.

Percentages given in Martin's statement above are calculated on a total of ten species from four localities, and the number of species is too small to be truly significant. *Turricula bataviana* Martin occurs at Bureau of Science locality F1054 near San Rafael, Agusan River, where it is associated with a fauna containing at least from 90 to 95 per cent Recent species.

My judgment concerning the age of this fauna is strongly influenced by a recent study made upon a fauna obtained from the Vigo group of Miocene age which contained an astonishingly large number of Recent species.

PLEISTOCENE

The beautiful Pleistocene limestones exposed at the end of the northwestern peninsula of Leyte offer an exceptional opportunity for the study of the conditions of formation of coralline limestone and allied problems. A cursory examination of these beds seems to indicate that most of the coral species still flourish in the neighboring waters. There are several marine terraces which denote successive uplifts, and each is covered by a thick deposit of coralline limestone. The underlying shales and sandstones of the Vigo group are exposed in a few places in the vicinity and the unconformity between these beds and the overlying Pleistocene limestone is well marked. The same relation exists between the horizontal Pleistocene deposits and the well-folded Malumbang coralline limestones and interbedded marls at a point about a half mile south of Baliti, a small barrio (village) on the west coast of Leyte. Likewise, along the road on the west side of Cebu from Barili to Alegria, may be seen beautiful exposures which clearly indicate a great time interval between the Pleistocene and the Malumbang Pliocene, thus negativing Becker's(50) tentative idea that—

> Ever since the later Miocene there has been a continuous, very slow, rise of the island [Cebu] and extension of its land area, raising above water successively Upper Miocene, Pliocene, and Pleistocene beds, the total uplift amounting to over 2,000 feet.

Cebu Island has had a much more complicated history.

Nearly all the large islands show distinct terracing in places, but attempts to correlate these terraces from island to island will lead to failure, since there are many evidences of Pleistocene

and Recent differential movements. These Pleistocene terraces are as a rule mantled by coralline limestone with which is associated a characteristic molluscan fauna, such as Plate 11 illustrates. Practically all of these Pleistocene species have representatives living to-day in these tropic seas.

Much work remains to be done upon the paleontology of the Philippines. Special effort should be made to search the older rocks more thoroughly for Paleozoic and Mesozoic fossils, and far larger collections from the Tertiary should be made than are now available. Especial attention should be paid to the study of the Tertiary, Pleistocene, and Recent corals in this inviting field for research. The lack of well-authenticated vertebrate fossils is noteworthy and any remains of vertebrates, such as those belonging to the horse and elephant families, would be very valuable in fixing in a more-definite manner the tentative age correlations now set forth. Careful studies of the distribution of plants and animals such as Mr. Elmer D. Merrill, director and botanist of the Bureau of Science, and Mr. R. C. McGregor, ornithologist of the same institution, are now carrying on in their respective lines will greatly aid in checking conclusions concerning the geology, paleontology, and paleogeography of the Philippines.

MINERALOGY *

In this chapter are discussed one hundred sixty-three mineral species and varieties comprising all those known with certainty to occur in the Philippines; the list published in 1915 gave one hundred thirteen. There are others the presence of which is suspected, but they have not been definitely identified. For instance, supposedly natural brass and diamonds are said to exist here, but no authoritative knowledge of them is at hand.

Practically all the minerals herein mentioned are represented in the collection of the Bureau of Science, and they have been collected for the most part during the American régime. The collections of the old Spanish mining bureau were almost worthless when they passed into the hands of the Americans. Whether the best specimens had been transferred elsewhere at the outbreak of hostilities is not known, but there is reason to suspect that this was done.

Three other mineral collections in the city of Manila have been consulted; namely, that of the Ateneo de Manila, of the Jesuit Order; that of the Santo Tomas University, of the Dominican Order; and that of the Ateneo de Rizal. Specimens of very few minerals were found in those collections that are not also represented in the Bureau of Science collection. As there is some doubt about the localities of some of the minerals in those collections, several species have purposely been omitted from my list. My acknowledgment of assistance from the curators of these institutions is hereby gratefully made, and also to Father Francisco de P. Sanchez, S. J., who has supplied me with many data with reference to localities.

It will be noted that many of the minerals in the following list have no economic value, but the fact that a substance has no present commercial value is no reason for excluding it from a catalogue. The future will undoubtedly see many minerals, now thought to be of little or no use to man, become of great commercial value. For instance, when the large deposits of

* This is a revision of the list of Philippine minerals by Smith, Eddingfield, and Fanning, Min. Resources P. I. for the year 1913 (1914) 56–71; reprinted in Philip. Journ. Sci. § A 10 (1915) 81–96.

concentrated iron oxides like hematite and limonite become exhausted, we shall be forced in all probability to turn to the iron-bearing silicates which are of too low a grade to be worked economically at the present time. Again, the mineral leucite, which contains about 21 per cent of potash, is a valuable prospective source of this important ingredient of the soil, but only recently has anyone thought seriously of extracting it.

Okamoto's list of minerals of Taiwan (Formosa) includes fifty minerals, about one-third as many as are included in the present list. Six of the Formosan minerals have not been found in the Philippines, while there are three others that are suspected to be here but that have not yet been certainly determined.

Mining men and students of the various schools and colleges are urged to send to the Bureau of Science specimens of minerals that they think new or interesting. It is reasonable to expect that when more persons become interested in this line the list will be greatly augmented. There are several thousand mineral species and varieties known in nature. The Bureau of Science is already greatly indebted to many of its friends of the mining community for valuable specimens.

It is to be regretted that no studies have been made of a strictly crystallographic or mineralogic nature, but more pressing investigations in the mining fields have made such a study impossible. The compilation of this list has suggested several subjects that can be profitably taken up by students of Philippine mineralogy.

I have given only the best-known localities under each mineral. Some are known from only one locality; while others, like gold, have been found in nearly every stream in the Archipelago.

CHECK LIST OF PHILIPPINE MINERALS

ACTINOLITE.—$Ca(Mg,Fe)_3Si_4O_{12}$.

This mineral occurs as acicular green crystals in the crystalline schists of Ilocos Norte. It is classed in the trade as one variety of asbestos. There is a small production in Ilocos Norte.

AGATE.—SiO_2.

Agate is found in many parts of the Archipelago where silicification has occurred. Occasionally specimens suitable for polishing are found. There is no production in the Philippines.

ALABASTER.—$CaSO_4.2H_2O$. See also Gypsum.

Gypsum forms at times in white or in tinted layers called alabaster. This has been reported from Batangas and Camarines Sur Provinces.

ALBITE.—See Plagioclase.

ALTAITE.—PbTe.

This mineral occurs in small quantities intimately mixed with sylvanite and free gold in specimens from the Tumbaga mine, Mambulao, Camarines Norte. It is tin white, sometimes with a bronze tarnish, and occurs as negative crystals or pseudomorphs after quartz crystals or fragments.

ALUM.—See Kalinite.

ALUMINIUM ORES.

Various clays containing fair percentages of aluminium oxide have led me to suspect the presence of aluminium ores, such as bauxite, but none has been found.

AMETHYST.—SiO_2.

Some large crystals have been found in Palawan, but this variety of quartz is not common in the Philippine Islands. When perfect it is used as a gem. One large amethyst crystal from Mount Tumarbong, Palawan, can be seen in the Santo Tomas museum. There is no production in the Philippine Islands.

AMPHIBOLE.—$RSiO_3$, R being more than one of the elements Ca, Mg, Fe, Al, Na, and K.

Found in Ilocos Norte and Bataan particularly. Very common in many igneous rocks. See Actinolite, Tremolite, Anthophyllite, and Hornblende.

ANALCITE.—$NaAl(SiO_3)_2+H_2O$.

This mineral occurs as an alteration product of leucite in some volcanic rocks of limited distribution on Masbate.

ANDESINE.—See Plagioclase.

ANDRADITE.—See Garnet.

ANORTHITE.—See Plagioclase.

ANTHOPHYLLITE.—$(Mg,Fe)SiO_3$.

This mineral is a variety of amphibole occurring in long, dirty white to brownish fibers, and is associated with serpentine and asbestos. It occurs in Ilocos Norte, where there was a small production until recently. In some cases it might be used as a substitute for asbestos.

APATITE.—$Ca_5(Cl,F)(PO_4)_3$.

Apatite occurs as large, yellowish to brown, six-sided crystals in small amounts, in metamorphic rocks near Pasuquin, Ilocos Norte, and also in minute crystals in many igneous rocks. It is valuable for fertilizer, if found in large enough quantities. There is no production in the Philippines.

ARAGONITE.—$CaCO_3$.

This mineral has been found so far in one locality, Talim Island, Laguna de Bay, in long clear crystals in vugs in basalt. It has no economic value here.

ARSENIC.—As (metallic).

This mineral is deposited in reniform masses, presumably from hot springs. It is found near Buguias, Benguet. Ores from Benguet contain small amounts of this mineral. There is no local use for arsenic ores.

ARSENOPYRITE.—FeAsS.

This is a silver white mineral that usually occurs in crystalline schists and serpentine and in veins, found in the Baguio region as fragments in quartz.

ASBESTOS.—$H_4(Mg,Fe)_3Si_2O_9$. (?)

Asbestos is associated with serpentine in Ilocos Norte. No first-grade asbestos has yet been found. It consists practically of longitudinal fibers. Several specimens of cross fiber (see Chrysotile) are in the Bureau of Science collection; one of these measures 3 centimeters. There is a small production in Ilocos Norte. It is found also in Zambales Province and near Silasa, Pangasinan Province. A small asbestos-products factory was operated in Manila until the middle of 1920, which consumed the entire local output of asbestos.

ASPHALTUM.—A complex series of hydrocarbons. See also Bitumens and Ozocerite.

One small specimen brought some years ago from the eastern cordillera, Luzon, is of doubtful authenticity.

AUGITE.—$(Mg,Fe)(Al,Fe)_2SiO_6$.

This mineral is one of the pyroxene group of silicates, common in certain igneous rocks like andesite. Augite has no economic value at present.

AZURITE.—$Cu_3(OH)_2(CO_3)_2$.

Azurite occurs as minute blue crystals in some copper deposits of Pangasinan and Batangas Provinces and in Mindanao. The deposits are as yet unimportant commercially.

BALTIMORITE.—$H_4Mg_3Si_2O_9$.

Baltimorite is a white to bluish, fibrous mineral associated with serpentine. It is found in Ilocos Norte. It might be used for steam packing and roofing material. There is little production in the Philippines.

BARITE.—$BaSO_4$.

Eveland reported barite from Mankayan as vein mineral.

BASONITE.—SiO_2.

This mineral is a velvet black variety of flint known as "touchstone" or "Lydian stone." It might be used for testing the purity of gold. There is one sample, No. 176, in the collection of the Ateneo de Manila.

BASTITE.—Practically of the composition of serpentine.

Noted by Oebbeke in a norite from "Minangas on the west side of the Cordillera of N. W. Luzon." It is a foliated pyroxene usually found only in basic igneous rocks. It is characterized by "schiller" structure.

BERYL (EMERALD).—$Be_3Al_2(SiO_3)_6$.

Small and imperfect specimens are reported from Mindanao, but nothing definite is known regarding the locality. One small specimen from Camarines is reported by Lednicky.

BIOTITE.—$(H,K)_2\ (Mg,Fe)_2Al_2Si_3O_{12}$.

Biotite occurs in various igneous rocks in the Philippines, in small crystals, principally in Paracale granite. In larger crystals yielding cherts it is very valuable. No economic deposits are known here.

BITUMINOUS COAL.—See Coal, Bituminous.

BITUMENS, NATURAL.—Various hydrocarbon residuals.

The natural bitumens of Leyte more nearly resemble ozocerite (which see) than any of the other bitumens. The Leyte products are derived from a paraffine-base petroleum; this distinguishes them from asphalt as most commonly defined. There is some true asphalt in the same region.

BLENDE.—See Sphalerite.

BORNITE.—Cu_5FeS_4.

Bornite occurs massive to finely crystalline in quartz veins. It is probably secondary in origin. This mineral is found in several of the copper deposits of the Islands. An excellent sample comes from the Quien Sabe claim, Suyoc, Mountain Province. Development work has been done on those deposits in the Philippines, but there is no production.

BRAISLAKITE.—A variety of amphibole.

A mineral very similar to this but not definitely determined was mentioned by Oebbeke in his description of some of the basalts and andesites from Taal Volcano, Luzon.

BRONZITE (ENSTATITE).—$(Mg,Fe)SiO_3$.

This orthorhombic representative of the pyroxene group was first noted by von Drasche in a decomposed condition in a rock from the Paracale district, Camarines Norte. It has been noted in other rocks by subsequent investigators. No use of this mineral is known.

BYTOWNITE.—See Plagioclase.

CALCITE.—$CaCO_3$.

Calcite as found in the Philippines is generally massive without crystalline faces, but some splendidly crystallized samples of "dogtooth" spar have been found. It is frequently associated with primary and secondary manganese minerals, and is also frequently associated with quartz in ore veins, there being a progression from quartz-calcite, probably the result of lowering of temperature and pressure. Calcite occurs also as a secondary mineral in igneous rocks and as stalactites and stalagmites in caves and travertine in streams. Marble is found in Romblon and crystallized limestone in Montalban. The mineral is used to manufacture quicklime for various industrial purposes. Marble is used for monuments and building purposes.

CASSITERITE (STREAM TIN).—(SnO_2).

Lednicky reports having panned stream tin from a stream in the interior from Bay, Palawan, about 75 kilometers south of Puerto Princesa.

CHALCANTHITE.—$CuSO_4 \cdot 5H_2O$.

This is a blue, fibrous, glasslike mineral, having a disagreable metallic taste. It occurs as an incrustation in the tunnels of the Mankayan mine, Lepanto Subprovince, deposited from the cupriferous mine waters.

CHALCEDONY.—$SiO_2 + H_2O$.

Chalcedony occurs in irregular, milky white patches in jaspers and other rocks in various parts of the Islands.

CHALCOCITE.—Cu_2S.

Chalcocite is a massive gray copper mineral usually secondary in the upper zones. It is found in Misamis, Mindanao, and in Mountain Province, Luzon. There is no production in the Philippines.

CHALCOPYRITE.—$CuFeS_2$.

Chalcopyrite is the most universally distributed ore of copper. It is found as small crystals in many quartz veins and is associated mainly with galena and usually crystallized after galena. It is found in small quantities in all of the mining districts. No commercial deposits are known in the Philippines.

CHERT.—SIO_2.

Chert occurs as nodules in various formations in many parts of the Archipelago; also as radiolarian cherts, probably of Jurassic age. It is well developed in Balabac, Palawan, Panay, and Ilocos Norte Provinces and is probably equivalent to the radiolarian "hornfels" of central Borneo. It is used elsewhere for road metal.

CHLORITE.—$H_8Mg_5Al_2Si_3O_{18}$.

Chlorite occurs as fine, green, fibrous masses as an alteration product in many igneous and metamorphic rocks. It has no economic use.

CHROMITE.—$FeOCr_2O_3$.

Chromite occurs associated with serpentine in heavy granular masses, with characteristic mottled, black and green appearance, in Antique Province, Panay. Near Dungon-Dungon, Ilocos Norte, it is found as bowlders, but confined to a very small area. Some prospecting has been done, but there is no production. Chromite is also found disseminated through serpentine near contact with granite on Lubang Island.

CHRYSOPRASE.—SiO_2, colored by nickel oxide.

Chrysoprase occurs as beautiful, leek-green pebbles in a river near Butuan, Mindanao. This mineral might be used as a gem. There is a specimen, No. 180, in the collection of the Ateneo de Manila.

CHRYSOTILE.—$H_4(Mg,Fe)_3Si_2O_9$.

Chrysotile occurs as white to greenish, silky fibers. Some fair specimens of the short cross fibers, from 2 to 3 centimeters in length, have been found in Ilocos Norte. Until recently, there has been a small production in this field.

CINNABAR.—HgS.

Minute red crystals of cinnabar were found in a few samples from Batwaan Creek, Benguet Subprovince, Luzon. Cinnabar remains in the pan with the gold. It is also reported from Busuanga Island and Mount Isarog, Camarines Sur. This mineral forms under surface conditions and is connected with volcanic activity. It is not mined in the Philippines.

COAL, BITUMINOUS.—Of complex composition, principally oxygenated hydrocarbons.

Bituminous coal is found in seams, from a few centimeters to several meters thick, in many parts of the Philippines, principally in Cebu and Mindanao. There are producing mines in Batan, Cebu, and Mindanao.

COAL, CRYSTALLIZED.

Anthracitized coal, exhibiting columnar crystallization, is found near Malangas, Mindanao. It is due to local metamorphism resulting from contact with igneous rocks.

COPALITE.—C,H,O, etc. Fossil resin.

Copalite is a soft, yellow and brown to white mineral with a resinous luster, found on Caramoan Peninsula, Camarines Sur, and in Zambales.

COPPER.—Cu (metallic).

Native copper occurs as irregular, partly crystalline masses and as round shot in alluvium; there are three type occurrences, namely: Amygdoloids in extrusives, in Masbate; in alluvials of Malaguit River, Camarines Norte; and (reported) in some quartz veins in Masbate. Native copper was probably used formerly by Igorots to make cooking utensils. It is not used at present.

CORUNDUM.—Al_2O_3. See also Ruby.

Corundum occurs as pebbles in placers at Peñaranda, Nueva Ecija, and at Paracale, Camarines Norte. These pebbles could be made into an excellent abrasive material.

COVELLITE.—CuS.

Covellite is an indigo-blue copper sulphide found in small amounts at Mankayan, Luzon.

CROCOITE.—$PbCrO_4$.

Crocoite occurs in characteristic, small, orange-red, monoclinic crystals at Labo, Paracale district, Camarines Norte. It is associated with galena-bearing rocks and is not abundant.

CUPRITE.—Cu_2O.

Cuprite occurs as small, clear, red crystals in the surface ore of a copper deposit in Antique Province, Panay.

DIALLAGE.—A nonaluminous pyroxene.

Diallage is a common constituent of gabbros in the Philippines. It has no economic value.

DIOPSIDE.—$CaMgSi_2O_6$. A variety of Pyroxene.

There is a doubtful occurrence of this rock-forming mineral in the Philippine Islands.

DOLOMITE.—$CaMg(CO_3)_2$.

Dolomite has been found associated with crystalline schists in Ilocos Norte. Itier mentions it from Angat, Bulacan Province. The limestones of the Philippines have little or no dolomite in them.

EMERALD.—See Beryl.

ENARGITE.—Cu_3AsS_4.

Enargite is probably secondary in copper deposits. It occurs massive and in small gray crystals with luzonite in the old Santa Barbara mine at Mankayan, Lepanto. It is mined and smelted by Igorots. Formerly there was considerable production by a Spanish company; at present it is not important. Some enargite is also known from near Kabayan, Benguet.

ENSTATITE.—See Bronzite.

EPIDOTE.—$HCa_2(Al,Fe)_3Si_3O_{13}$.

Epidote is apparently not common in the Philippines. It occurs as yellowish grains or in more or less amorphous masses in a few igneous rocks. It has no economic value.

EPISTILBITE.—$H_4(Ca,Na_2)Al_2(SiO_3)_6 \cdot 3H_2O$.

This white silicate has been found in Bulacan Province, Luzon. There are specimens in the collection of the Bureau of Science. There is no use of this mineral known.

FELDSPAR.—See Orthoclase and Plagioclase.

FIBROLITE (SILLIMANITE).—Al_2SiO_5.

Orthorhombic prisms of fibrolite are found in the gabbros of Panay. It is not an economic mineral.

FLINT.—SiO_2.

Flint is a compact form of silica, usually dark brown to black. It occurs in Samar, usually as bowlders. Chert is a synonym.

GALENA.—PbS.

Galena, as a rule, is crystallized with strong cubic cleavage and is bluish gray. In the Philippines it is associated with zinc and pyrite in quartz veins, rarely in calcite veins. It frequently carries silver, but rarely gold. This mineral is found in veins in Batangas, Cebu, Marinduque, Paracale, Masbate, and Surigao and in Suyoc, Mountain Province. During the Spanish régime galena was mined to a limited extent in Cebu, but it is not mined at present.

GARNET.—Complex silicates with Fe, Mg, Mn, and Ca as interchangeable bases.

The common species, andradite, occurs rarely in the Philippines as minute, wine-red granules in a rock from Bulacan Province, Luzon. It has no economic value.

GOLD.—Au (metallic).

Gold occurs associated with pyrite and, rarely, with galena. It usually occurs as the pure yellow metal in quartz and in calcite veins as wires, plates, grains, and crystals; abundantly distributed in placer as perfect crystals, wires, and rounded grains, and occasionally found as nuggets that weigh from 10 to 30 grams. Traces of gold are found in most rocks that carry pyrite. Gold is found in paying quantity in veins in Suyoc and Baguio, Mountain Province; Paracale and Mambulao, Camarines Norte; and Aroroy, Masbate. It is found in paying quantity in placer in Suyoc, Mountain Province; Peñaranda district, Nueva Ecija; Umirey, Tayabas; Paracale, Mambulao, and Malaguit, Camarines Norte; Cansuran, Surigao; Hibong River and localities along Agusan River in Mindanao; in Misamis Province; and in Mindoro.

GRAHAMITE.—See Bitumens.

GRAPHITE.—C.

Graphite is reported as occurring in "graphite clay" in Bulacan Province, Luzon. It is also reported from Alabat Island, Tayabas Province.

GUANO.—P_2O_5 with impurities.

Guano occurs as a coarse brownish earth (largely bat excrement) in limestone caves in many parts of the Archipelago, principally along seacoasts. A small amount is collected and sold to Japanese exporters.

GYPSUM.—$CaSO_4$.

Gypsum occurs generally in small tabular crystals as incrustations on volcanic rocks near solfataras; as incrustations in cleats of some Philippine coals; and in finely granular form in the Loboo Mountains, Batangas Province. Another locality is near Nabua, Camarines Sur. There is a small production from Talahib, Batangas Province. It is shipped to Cebu to the cement works.

HALITE.—See Salt.

HEMATITE.—Fe_2O_3.

Hematite is found in irregular "pockets" with magnetite, pyrite, chalcopyrite, and quartz in crystalline rocks of the eastern cordillera of Luzon; also, in veins cutting limestone. It occurs from Mambulao Bay, Camarines Norte, to northern Bulacan Province, Luzon. The grade of this ore is excellent. It is smelted by Filipinos in crude blast furnaces to make plowshares.

HORNBLENDE.—$Ca(Mg,Fe)_2(SiO_3)_3$.

Hornblende is abundant in many igneous rocks as black crystals, from microscopic to 2 or 3 centimeters in length. It is of no economic value.

HYACINTH.—$ZrSiO_4$. See also Zircon.

Reported by Karuth from Mindanao. (350).

HYPERSTHENE.—$(FeMg)SiO_3$.

Hypersthene occurs in certain varieties of andesite in many localities. It is distinguished by its pleochroism (colorless to delicate pink) under the microscope. Hypersthene has no economic value.

IDDINGSITE.—Exact composition not known.

Iddingsite occurs as a red alteration of olivine in rocks from three localities; namely, the Batanes, Mindoro, and Mount Mariveles, Bataan Province. The mineral was named for the late J. P. Iddings, the great authority on igneous rocks. It has no economic value.

ILMENITE.—$(Mg,Fe)TiO_3$.

Ilmenite is found in black-sand concentrates in many streams throughout the Archipelago, usually in small crystals and more or less rounded grains. It is not utilized.

IRIDIUM.—Ir (metallic).

The occurrence of iridium is the same as that of osmium.

JAMESONITE.—$Pb_2Sb_2S_3$.

Reported by Pratt from the Cansuran property, Surigao, Mindanao.

JASPER.—SiO_2.

Jasper occurs in fissile beds, in irregular masses, and bowlders. It contains remains of radiolarian tests. The color is brown to deep red. It is silica, largely stained with iron oxide.

KALINITE (ALUM).—$K_2SO_4.Al_2(SO_4)_3+24H_2O$.

Kalinite occurs in mealy crusts around solfataras at Taal Volcano, Luzon, and elsewhere, apparently in small quantities.

KAOLINITE.—$Al_2O_3.2SiO_2.2H_2O$.

Kaolinite occurs in the Philippines, usually as a solfataric decomposition product of andesitic rocks; it is rarely pure. In the region around Laguna de Bay, Luzon, it is found in irregular "pockets." Kaolinite is used to a moderate extent in making pottery and for a local paint, so-called "yeso," which is the Spanish equivalent for gypsum. Some good samples from Talingting, near Dumaguete, Oriental Negros, are in the collection of the Bureau of Science.

LABRADORITE.—See Plagioclase.

LEAD.—Pb (metallic).

Native lead was reported by Minard as occurring in flakes in the gold placers of Misamis, Mindanao. It is probable, however, that this can be traced to ammunition expended during Spanish times.

LEUCITE.—$KAl(SiO_3)_2$.

Leucite occurs partially altered to analcite in certain very limited exposures of volcanic rock in the Aroroy district, Masbate. These rocks contain from 8 to 10 per cent of potash, which might be made available for fertilizer, though it would hardly be economic at present.

LIGNITE.—Various hydrocarbons.

True lignite is found, varying in thickness from a centimeter to several meters and grading into a subbituminous coal. It occurs in many parts of the Archipelago. It usually crumbles into small cleavage cubes and air slacks. Its woody texture is seen best in weathered specimens. Much of the coal mined and marketed in the Islands is lignite.

LIMONITE.—$2Fe_2O_3.3H_2O$.

Limonite is associated with hematite and is found near the surface; it occurs also in small pisolitic granules. It is distributed in small amounts throughout the Archipelago. Sometimes limonite is used in small quantities in making paint. Excellent pseudomorphs of limonite after pyrite cubes occur in schists of Ilocos Norte. Limonite, when used as a pigment, is called yellow ocher.

LODESTONE.—See Magnetized iron ore.

LUZONITE.—Cu_3AsS_4.

Luzonite is apparently a secondary ore of copper and it is a special form of enargite.(454) It forms in vugs and cracks in the vein. Luzonite is found in Mankayan, Mountain Province, and constitutes a large percentage of the enriched portion of the veins.

MAGNESITE.—$MgCO_3$.

Magnesite occurs associated with serpentine in Ilocos Norte, as a white, earthy mineral, which is efflorescent. It is reported from Bulacan Province and from Negros. No use is made of it.

MAGNETITE.—Fe_3O_4.

Magnetite is widespread in small particles throughout the igneous rocks in the Philippines. It is associated with the hematites of the eastern cordillera, Luzon. There are some fine octahedral crystals (No. 319) from San Miguel de Mayumo, Bulacan, in the collection of the Ateneo de Manila. Perfect octahedrons are numerous in the magnetite schists of Ilocos Norte. Magnetite sands from the Bataan coast were for a time briquetted and smelted, but the project finally was abandoned.

MAGNETIZED IRON ORE.—Lodestone. Apparently iron oxides.

This ore is found near Paracale, Camarines Norte, and is also reported from near Casiguran, Tayabas. No deposits are worked.

MALACHITE.—$(Cu{\cdot}OH)_2CO_3$.

No large crystalline samples of malachite are recorded. This mineral is present in most of the copper deposits as a green coating.

MANGANITE.—$MnO(OH)$.

Manganite occurs possibly with wad and pyrolusite in mineral veins, and often contains high values in gold. It is soft and is derived from other manganese ores. It is found in several veins in Baguio and Suyoc, Mountain Province, and in Aroroy, Masbate. It has no economic value in the manner of its occurrence in the Philippines.

MARBLE.—$CaCO_3$. See also Calcite.

Some marble from Romblon was used in the construction of the new executive offices of the Governor-General in Manila.

MARCASITE.—FeS_2.

Marcasite is similar to pyrite, but is whiter. It is apparently infrequent. Marcasite has been reported from Mankayan, Mountain Province, and from Samar.

MARGARITE.—$H_2CaAl_4Si_2O_{12}$.

Margarite is a white mica occurring in certain schistose rocks of Ilocos Norte. No use is made of it.

MELACONITE.—CuO.

Near San Remigio, Antique Province, this earthy, black, massive copper oxide is found associated with native copper, cuprite, and malachite.

MERCURY.—Hg (metallic).

Mercury is reported to occur in small crevices and pockets on Mount Isarog, Albay Province, and also in Panay. There is a small phial of it in the museum of the Ateneo de Manila. Only Negritos have seen the locality where it is supposed to be obtained.

MICA.—Various aluminum silicates. See Biotite, Muscovite, Margarite, Parangonite, Sericite, Vermiculite, and Phlogopite.

MINIUM.—PbO.

There is a large, amorphous, pink specimen of this mineral in the museum of Santo Tomas University, marked "Filipinas;" no data are given.

MOLYBDENITE.—MoS_2.

Molybdenite is found in characteristic form in steel-blue flakes and leaves in quartz veins in the Loboo Mountains, Batangas Province. Only a small amount is found. It occurs also in Benguet Subprovince.

MUSCOVITE.—$K_2O.3Al_2O_3.2H_2O$.

Muscovite occurs rarely in igneous rocks. It occurs more commonly in schists, particularly in a quartz muscovite schist in Camarines Sur. Well-developed mica schists have been noted in Ilocos Norte. There is no economic deposit of this mineral in the Philippines.

NEPHELINE.—$(Na_2,K_2Ca)_4Al_8Si_9O_{34}$.

Nepheline is found, according to Abella, in certain igneous rocks on Panay, usually associated with feldspar and biotite. It is not known to occur with quartz.

NITER.—KNO_3.

Niter is said to be collected from certain caves on a small island near Surigao, Mindanao, and is used for making gunpowder. It has also been reported from Bontoc, Mountain Province. The Bureau of Science has no definite information regarding this substance in the Philippines.

OCHER.—Impure iron oxides.

The ochers found in Ilocos Norte are iron oxides in various stages of hydration; the yellow is limonite, the red, hematite. There is no production.

OLIGOCLASE.—See Plagioclase.

OLIVINE.—$(Mg,Fe)_2SiO_4$.

Olivine occurs in many rocks in the Islands, particularly in small, greenish yellow grains in basalt and in so-called picrites of Panay. It is of no economic value.

OPAL.—SiO_2H_2O.

Opal is found in small fragments and, occasionally, in large pieces of jasper. It occurs in Ilocos Norte and various other provinces, but is of no commercial value as found in the Philippines. There is a pretty specimen showing "fire" in the museum of Santo Tomas University, but the locality is doubtful. Some opals of small value have been recently reported from Iloilo Province.

ORTHOCLASE.—$K_2O \cdot Al_2O_3 \cdot 6SiO_2$.

Orthoclase occurs sparingly in some igneous rocks. It is of no economic use here.

OSMIUM.—Os (metallic).

Osmium occurs with gold, iridium, and traces of platinum in thin metallic plates in decomposed rock. It is said that the mineral is found in Luzon, but the exact locality is unknown to us.

OZOCERITE.—Complex hydrocarbon.

Ozocerite, largely composed of paraffine and some ceresin, makes up the bulk of the natural bitumen that is found in the northern part of Leyte near Villaba, adjacent to petroleum seeps in Miocene shale, sandstone, and limestone. This is being mined and exported in large quantities and is also used on Philippine roads.

PARAGONITE.—$H_2NaAl_3(SiO_4)_3$.

Paragonite, a variety of mica, is found with the schists of Ilocos Norte.

PENNINE (PENNINITE).—$H_8Mg_5Al_2Si_3O_{18}$.

Pennine has been noted in the "Thetford" workings in Ilocos Norte with muscovite, biotite, margarite, phlogopite, and talc, mixed in pockets and along shearing planes.

PETROLEUM.—Complex series of hydrocarbons.

Petroleum in the Philippines occurs as a very light, paraffine-base oil in shales in various parts of the Islands, notably in Mindanao, Leyte, Cebu, and in Bondoc Peninsula, Tayabas Province, Luzon. Several shallow wells that have been dug have yielded little more than samples of oil. A large company with modern equipment is drilling on Bondoc Peninsula.

PHILIPPSITE.—$(K_2,Ca)Al_2Si_4O_{12}+4\frac{1}{2}H_2O$.

Philippsite occurs in characteristic white, radiating or tuffed masses in Masbate. No economic use is made of it.

PHLOGOPITE.—$(H,K)_3(Mg,Fe)_3(Al,Fe)(SiO_4)_3$.

Phlogopite occurs in Ilocos Norte in the crystalline schist area.

PICKERINGITE (MAGNESIA ALUM).—$MgSO_4.Al_2(SO_4)_3+22H_2O$.

Pickeringite is found in long fibrous masses as efflorescences in the old Santa Barbara copper mine, Mankayan, Lepanto Subprovince; it also occurs on Camiguin Island, north of Luzon.

PICOTITE.—$(MgFe)O(AlFeCr)_2O_3$. A variety of spinel.

Noted by Oebbeke(462) in a peridotite from near Palanan in northeastern Luzon. It is one of the rarer accessory rock minerals.

PLAGIOCLASE.—$NaAlSi_3O_8$ to $CaAl_2Si_2O_8$.

This series of closely related minerals is one of the commonest of all the constituents of igneous rocks in the Philippines. It embraces the following species: Albite, anorthite, andesine, bytownite, and labradorite. It has no known economic value.

PLATINUM.—Pt (metallic).

Platinum is found in minute flattened grains in placer-test borings near Peñaranda, Nueva Ecija; on Mariquina River, Rizal; and in Agusan Valley and Misamis, Mindanao. There is no production in the Philippines.

PROCHLORITE.—$H_4(Mg,Fe)_2Al_2SiO_9$.

Prochlorite occurs in dirty green leaves, which are flexible but not elastic. It is found in the metamorphic area of Ilocos Norte. No use is made of it.

PSILOMELANE.—H_4MnO_5. The manganese is commonly replaced in part by barium or potassium.

Psilomelane occurs associated with pyrolusite. It is a very impure ore of manganese, often containing only 40 per cent of that element. (See Pyrolusite.)

PYRITE.—FeS_2.

Pyrite occurs both massive and crystalline. The mineral appears as disseminated grains and as large crystals. Pyrite is often cupriferous. It is persistent in quartz veins and occasionally in calcite veins and is in many places associated with gold. It is also often associated with galena and zinc. This mineral is also commonly disseminated in volcanic rocks. There are specimens of large secondary (?) crystals from Malaguit River, Camarines Norte, in the Bureau of Science collection. Pyrite forms under conditions ranging from deep to surface. It is the most widely distributed metallic mineral, being found in almost all rocks. There is no commercial use of pyrite in the Philippines. Its chief use in the United States is for the manufacture of sulphuric acid.

PYROLUSITE.—MnO_2 with 2 per cent H_2O.

Pyrolusite is the principal ore of manganese in the Philippines. It occurs in botryoidal or massive shapes; also reniform. It is found as veinlets in andesite and as nodules from erosion of veins. It is found in Ilocos Norte, Pangasinan, Bulacan, Tarlac, and Masbate Provinces. In Masbate it is found in lenses interbedded with Kaal slates. It is not exploited.

PYROXENE.—$Ca(Mg,Fe)Si_2O_6$.

Pyroxene is a common constituent of pyroxene andesite, one of the chief rock types in the Islands. It occurs in small, jet-black crystals. It has no economic value.

QUARTZ.—SiO_2.

Quartz is the chief mineral composing the outer shell of the earth. It occurs in fine crystals in vugs under proper conditions; otherwise, it generally takes the form of jasper, chert, or siliceous sinter at the surface.

It occurs in veins and as silicification of wall rocks and is the principal gangue mineral in the gold veins of the Philippines. Only two workable deposits of quartz, for the quartz alone, are known; namely, siliceous spring deposits, at Baguio; and beach sand, at Looc, Lubang Island. Quartz is used locally as road material and in concrete in Baguio and at Looc. It might be used for glass making.

REALGAR.—AsS.

Realgar occurs as characteristic red crystals on a yellow coating of orpiment in pieces of slag (?) from the old Santa Barbara furnace at Mankayan, Luzon. There are specimens, No. 59, of realgar in the museum of the Ateneo de Manila. A fine specimen of orpiment with realgar, from the barrio of Malaga, Tinambakau, Samar, is in the Bureau of Science collection.

RHODOCHROSITE.—$MnCO_3$.

Rhodochrosite occurs as a gangue mineral in auriferous calcite veins of Benguet. It is a primary (?) mineral; it was probably leached from wall rocks by ascending solutions and was later deposited with the calcite. Rhodochrosite is of no economic use, and can hardly be regarded as a source of manganese.

RUBY.—Al_2O_3. See Corundum.

Reported by Karuth from Mindanao.

RUTILE.—TiO_2.

Microscopic crystals occur in some of the metamorphic rocks from Ilocos Norte associated with actinolite, muscovite, and other minerals. Rutile has no economic value.

SALT.—NaCl.

Salt is deposited as an incrustation from hot, brackish, carbonated springs in Mountain Province, Luzon, notably at Asin and Mainit. It is used by the Igorots.

SANIDINE.—$(K,Na)AlSi_3O_8$.

Sanidine occurs in small crystals and grains. This "glassy feldspar" is a dominant constituent of the trachytes and of the andesites of many peaks in Zambales Mountains and on Mount Apo, Mindanao. It is of no economic value.

SARDONYX.—SiO_2.

A specimen of this, No. 174, from Baganga, Mindanao, is in the collection of the Ateneo de Manila.

SERICITE.—$3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$.

Sericite is one of the micas occurring in the schists of Ilocos Norte and of Zamboanga Peninsula. It occurs in small, gray-blue, silky flakes. It is of no economic use.

SERPENTINE.—$H_4(Mg,Fe)_3Si_2O_9$.

Serpentine, the alteration from pyroxenites and peridotites in more or less structureless masses, is found in Ilocos Norte and other localities. It is a greenish mineral. Various asbestiform minerals as well as true asbestos usually occur with serpentine. There is a small production in Ilocos Norte.

SIDERITE.—$FeCO_3$.

Found in some lodes in the lower part of Antamok Valley, Benguet, in compact and earthy fragments. Color, brown. Not very prominent.

SILLIMANITE.—See Fibrolite.

SILVANITE.—$(AuAg)Te_2$.

Silvanite occurs intimately mixed with the lead telluride, altaite, in quartz and calcite stringers in a contact between a slaty formation and a feldspar-porphyry dike in Paracale.

SILVER.—Ag (metallic).

Silver generally occurs in the Philippines only in natural alloys with gold and associated with the mineral galena. The gold from both placers and lodes in the Philippines carries silver varying in quantity up to 30 per cent. Silver-bearing galena is found at Panopoy, Cebu, and near Paracale, Camarines Norte. Some native silver has been recently reported from Benguet.

SPAR.—See Calcite.

SPHALERITE.—ZnS.

Sphalerite occurs massive or as small crystals, always associated with lead and pyrite. Like the other sulphides, it favors the quartz veins; it forms under conditions of moderate depth. It occurs in practically all localities where galena is found (see Galena). The known deposits of sphalerite are not economically valuable, although the mineral is widely found in many gold veins, where it is usually regarded as a hindrance. It is not utilized in the Philippines.

SPHENE.—See Titanite.

STIBNITE.—Sb_2S_3.

Stibnite occurs in characteristic fibrous masses. There is only one specimen in the Bureau of Science collection, from Batangas Province, Luzon.

SULPHUR.—S.

Sulphur occurs, more or less pure, in characteristic yellow crystals around solfataras and also in a very impure state mixed with volcanic ash on Camiguin Island, north of Luzon; on Taal Volcano and in Sorsogon, Luzon; on Mount Apo, Mindanao; on Biliran and Leyte; and at Silay, Occidental Negros. No sulphur is mined at present, but some mines on Biliran were formerly worked.

TALC.—$3MgO.4SiO_2.H_2O$.

There are small amounts of talc associated with mica and actinolite in the metamorphic region of Ilocos Norte. It is common in some mineral veins in Camarines Norte. No local use is made of this mineral.

TENORITE.—See Melaconite.

TETRAHEDRITE.—$4Cu_2S.Sb_2S_3$.

Tetrahedrite occurs as flint-gray to tin-black crystals. It is found at the old Santa Barbara mine in Mankayan, Lepanto, and is reported by McCaskey (?) from Palawan.

TIN.—See Cassiterite.

TITANITE.—$CaTiSiO_5$ or $CaO{\cdot}TiO_2{\cdot}SiO_2$.

Titanite occurs as characteristic wedge-shaped crystals associated with the iron-ore deposits of Bulacan Province. Sphene is found intergrown with plagioclase in quartz-diorite from near Sara, Iloilo (reported by Iddings).

TOPAZ.—$(AlF)_2SiO_4$ or $(Al(F,OH)_2\ SiO_4$.

Topaz occurs in small (2 to 4 millimeters), pink, yellow, or colorless orthorhombic crystals, in placers of Paracale River, Camarines Norte.

TRAVERTINE.—$CaCO_3$.

Travertine as a stream deposit is widespread in the limestone regions of the Philippines, and is usually deposited on shale.

TREMOLITE.—$CaMg_3(SiO\)_4$.

Tremolite occurs in long, white to greenish fibers associated with serpentine and asbestos in Ilocos Norte. It is reported from Bataan Province. It is used commercially in Manila.

TRIDYMITE.—(SiO_2).

Noted by the petrographer Oebbeke in andesites from Mount Mariveles, Bataan.

URALITE.—Composition same as pyroxene except for slight change in magnesium and calcium content.

Uralite is a green alteration product of pyroxene and is found in certain igneous rocks called metadiorites, which are altered gabbros.

VAUQUELINITE.—$2(Pb,Cu)CrO_4{\cdot}(Pb,Cu)_3P_2O_8$. (?)

This is a soft, brittle mineral found in quartz veins in hornblende schist near Mambulao, Camarines Norte.

VERMICULITE.—Hydrated mica.

Vermiculite is an earthy mica found in the metamorphic area of Ilocos Norte. It has no economic value.

WAD.—An earthy mixture of manganese oxides.

Wad is found in association with psilomelane and pyrolusite. It is of no economic importance in the Philippines.

WERNERITE.—Intermediate between $Ca_4Al_6Si_6O_{25}$ and $Na_4Al_3Si_9O_{24}Cl$.

Wernerite is a white, fibrous silicate, and occurs in veinlets in greenstone in Aroroy district, Masbate. No use is made of it.

WOLFRAMITE.—(FeMn)WO_4.

Wolframite is a heavy, black, crystalline mineral. One specimen was found by Lednicky in the hills east of Bugasong, Antique Province, Panay. There is no economic development.

ZEOLITE.—Composition uncertain. $RAl_2S_{10}O_{24}$.

Zeolite occurs as a fibrous secondary product in the decomposition of certain rock minerals, principally feldspars, and in amygdoloidal cavities in igneous rocks throughout the Islands. The mineral has no known use.

ZINCBLENDE.—See Sphalerite.

ZIRCON.—Zr (metallic).

Zircon was noted by Daubre in sands from Mindanao.

ECONOMIC GEOLOGY

Of the three basic industries, mining, agriculture, and forestry (the tripod that directly supports our material civilization and indirectly our whole physical, intellectual, and moral life), the first has been tardiest in development in the Philippines.

American capital, with good reason, has for a number of years been chary about going outside the United States to seek investment, so that the industry here has depended and must, to a large extent, still depend upon New Zealand, Australian, and China Coast capital. Dredging operations have been largely in the hands of New Zealanders.

There are indications that the Filipinos are becoming aware of their long neglect of this important branch; Filipino prospectors are beginning to come in more and more with their finds. Although some of them are engaged in crude coal, gold, and iron mining in a small way in a few localities, there is no private company of Filipinos engaged in the business on a large scale. The Government of the Philippine Islands, the majority of whose responsible officials are Filipinos, is now sponsoring several national mining projects, but these are still in the developmental stage.

It has been said many times that mining in the Philippines is not a poor man's game. This is true, except in gold mining, in which it is possible to make "better than wages" with very limited capital. There are not only a few Americans engaged in this sort of mining, but also hundreds of Filipinos get a livelihood by panning the streams. Most of the metalliferous deposits are low grade and refractory. There are exceptions, of course, such as the rich gold placers of the Paracale district, which are now almost exhausted, and the lode that is being worked by the Benguet Consolidated Mining Company.

The Philippine mineral products in the order of their money-value production are gold, salt, stone, coal, sand and gravel, lime clay (pottery), clay (brick and tile), iron ore, mineral waters, bituminous rock, silver, and sulphur.

In Table 25 the mineral production of the Philippine Islands by years, from 1907 to 1920, is recorded. In Table 26 the

TABLE 25.—*Mineral products for the Philippine Islands, for the calendar years 1907 to 1920, inclusive.*

[Values in pesos Philippine currency. [a]]

	1907	1908	1909	1910	1911	1912	1913	1914
Metals:								
Copper	(b)	52	(b)	464	600	(b)	(b)	(b)
Gold	187,647	434,500	495,194	308,860	379,906	1,140,424	1,736,724	2,349,267
Iron	19,536	17,500	31,078	20,023	29,159	49,272	64,471	56,274
Manganese	(b)	(b)	12,500	(b)	(b)	(b)	(b)	(b)
Silver [d]	97	2,750	3,120	1,944	3,606	8,664	(b)	9,878
Total	207,280	454,802	541,892	331,291	413,271	1,198,360	1,801,195	2,415,419
Nonmetals:								
Asbestos	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
Bituminous rock (asphalt)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
Cement	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
Coal	26,799	77,166	197,184	176,255	*130,000	20,200	(b)	(b)
Clay products (brick, tile, pottery) [f]	(b)	421,628	422,840	430,000	450,000	453,000	460,000	465,000
Lime	(b)	20,000	69,656	70,000	90,000	92,026	102,700	100,000
Mineral waters	(b)	53,688	80,200	46,000	60,000	55,849	60,000	50,000
Salt	(b)	(b)	375,368	380,000	550,000	574,511	575,000	590,000
Sand and gravel [g]	(b)	206,360	325,050	293,456	477,344	468,758	595,645	625,429
Stone	(b)	149,930	311,177	372,575	655,795	651,049	350,041	367,543
Sulphur	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
Total	26,799	928,772	1,781,475	1,768,286	2,413,139	2,315,393	2,143,386	2,197,972
Grand total	234,079	1,383,574	2,323,367	2,099,577	2,826,410	3,513,753	3,944,581	4,613,391

	1915	1916	1917	1918	1919	1920	Total.
Metals:							
Copper	(b)	(b)	(b)	(b)	(b)	(b)	1,116
Gold	2,633,528	3,011,755	2,645,784	2,575,970	2,619,449	2,424,606	22,943,614
Iron	22,694	18,864	17,936	24,983	[c] 127,954	40,191	539,935
Manganese	(b)	30,000	(b)	9,000	(b)	(b)	51,500
Silver [d]	15,665	7,576	4,895	8,306	18,828	19,261	104,590
Total	2,671,887	3,068,195	2,668,615	2,618,259	2,766,231	2,484,058	23,640,755
Nonmetals:							
Asbestos	(b)	(b)	(b)	5,250	37,500	(b)	42,750
Bituminous rock (asphalt)	(b)	(b)	(b)	(b)	21,000	30,005	51,005
Cement	(b)	(b)	(b)	(b)	124,752	(b)	124,752
Coal	(b)	(b)	141,425	385,400	822,300	1,452,200	3,428,929
Clay products (brick, tile, pottery) [f]	475,000	685,078	900,000	910,000	700,000	570,880	7,343,426
Lime	144,000	153,075	270,000	375,000	534,000	10,872	2,031,329
Mineral waters	55,000	82,994	63,950	50,000	60,000	121,259	838,940
Salt	600,000	742,500	780,000	900,000	900,000	1,401,307	8,368,686
Sand and gravel [g]	580,580	587,547	788,508	724,591	588,379	1,228,332	7,489,979
Stone	341,119	344,871	417,952	553,714	832,630	[h] 311,861	5,660,257
Sulphur	(b)	(b)	(b)	11,140	1,680	(b)	12,820
Total	2,195,699	2,596,065	3,361,835	3,915,095	4,622,241	5,126,716	35,392,873
Grand total	4,867,586	5,664,260	6,030,450	6,533,354	7,388,472	7,610,774	59,033,628

[a] One peso Philippine currency normally is equal to 50 cents United States currency.
[b] Statistics not available; in most cases, no production.
[c] Includes iron ore; statistics elsewhere represent manufactured products.
[d] Silver is generally found alloyed with gold; none is mined separately.
[e] Twenty thousand metric tons at 6.50 pesos per ton.
[f] The manufacture of clay products is largely a household industry, so that exact figures are difficult to obtain. The present figures are estimated from figures furnished by the Bureau of Commerce and Industry and by various provincial officials.
[g] Principally road materials.
[h] Building and ornamental stone only.

Philippine imports and exports of coal, iron, etc., for 1920, are recorded. In Table 27 the coal imports by countries, for 1920, are shown.

TABLE 26.—*Philippine imports and exports of coal, iron, cement, earthen stone and chinaware, fertilizers, and salt for the year 1920.*

[Compiled by the statistical division of the Bureau of Commerce and Industry.]

Article.	Exports.		Imports.	
	Quantity.	Value.	Quantity.	Value.
	Kilos.	*Pesos.*	*Kilos.*	*Pesos.*
Coal [a]	[b] 254,000	6,000	540,055,501	10,792,077
Iron		74,504		43,759,204
Cement			85,981,210	3,240,458
Earthen stone and chinaware				962,516
Fertilizers			1,810,720	325,156
Salt	3,622,729	101,862	156,634	24,260

[a] Not classified by grade. [b] Coal exports, to Hongkong.

TABLE 27.—*Philippine coal imports for 1920.*

[Compiled by the statistical division of the Bureau of Commerce and Industry.]

Country.	Quantity.	Value.
	Kilos.	*Pesos.*
United States	14,780,506	162,029
Australasia	100,569,881	1,429,982
British East Indies	34,744,832	737,613
Dutch East Indies	380,648	1,880
French East Indies	958,088	12,511
Japan	325,963,048	7,408,949
China	62,658,498	1,039,113
Total	540,055,501	10,792,077

FACTORS AFFECTING MINERAL DEVELOPMENT IN THE PHILIPPINE ISLANDS

The following factors seem to be the most important in their effect upon the development of the industry in this Archipelago: Political status, general world conditions, laws and regulations, taxes, capital, costs, transportation, geologic conditions, labor, personnel, and hygiene.

Political status.—As mining is perhaps the most sensitive of all the industries, it is the first to respond to change in economic conditions. The risks inherent in the business are sufficiently great to make those who follow it as a business doubly cautious.

When additional risks, such as those attendant upon uncertain political status, are to be faced, those who look upon mining as a business and not as a gamble may not care to invest their capital. Therefore, political stability is the first essential for the mining industry.

General world conditions.—The Philippines did not escape the mushroom prosperity or the subsequent deflation growing out of the World War. In some lines at least the mining industry will go forward, perhaps slowly, now that many men have been thrown out of work and the need for gold is becoming acute. The decrease in prices will also have a beneficial effect, since the purchasing power of gold has consequently risen. Therefore, we may look for an increase in activity in both the gold and the coal branches of the industry; but in copper, iron, manganese, etc., the Philippines will not show much activity for some time.

Laws and regulations.—There are two schools of thought on the subject of mining laws; both are sincere and have good arguments to support their respective contentions. The conflict is between those with strong individualistic tendencies and those with a more social (I purposely avoid the use of the word "socialistic") outlook on life.

The Act of Congress of 1902, which is a modification of, and a decided improvement on, the United States law (its parent and model), still holds for the metals; but, in the case of coal and petroleum, the leasing system has been adopted by the Government of the Philippine Islands.

In addition to lack of uniformity in the laws controlling the development of the different classes of deposits, which a complete revision would remedy, there are some provisions in the present laws which should be cleared away, particularly as they are constantly being evaded. One of these is the provision that a person or corporation can take up only one claim on a lode (Sec. 33); and the second (Sec. 56), that a person interested in one mining corporation cannot become interested in any other. The practical effect of the last-named provision would be to prevent any person successful in one venture from bringing his experience and special talents to bear upon other projects in this difficult field. It amounts to penalizing efficiency.

As both of these restrictions were commented upon by Mr. McCaskey, the second chief of the Mining Bureau, as long ago as 1905, all the very strong arguments which can be made

against them need not be repeated. The proposed new mining law will eliminate both of these sections.

Taxes.—The whole question of mine taxation is a moot one in many countries. The chief trouble arises from the fact that persons unacquainted with the industry control the levying of taxes. A second source of trouble is the natural desire of governments to derive as much income as possible from the industry.

Non-producing mineral land in some instances has been assessed at an unreasonably high valuation, and the effect has been to discourage development.

Capital.—In the Philippines the mining business has had to depend upon small amounts of locally raised money, supplied chiefly by Americans, or capital has come from New Zealand, Australia, and the China Coast. Filipinos have been very reluctant to risk their money and, consequently, they have had little share in the benefits that have so far accrued. American capital from the United States has been very chary about going so far afield.

Costs.—Costs of supplies, freight charges, skilled superintendence, depreciation, and maintenance are all excessive in this part of the world, as the following statements indicate: It costs as much to ship a ton of freight from Manila to Paracale as from New York to Manila; few of the interisland boats are able to handle heavy machinery; lighterage charges at places without loading facilities are often as high as 20 pesos per ton; skilled employees, in some lines, brought from the United States are working on 25 per cent bonus, plus subsistence.

Transportation.—In spite of the great strides that have been made in the Philippines within the past dozen years in the matter of transportation facilities, many parts of the Archipelago are without adequate means of communication. The following are some of the highways urgently needed to promote the development of the interior regions: From Baguio through the Mountain Province to Aparri; along the east coast of Luzon; and from Malaybalay, Bukidnon, to Fort Pikit by way of Banisilan.

Geologic conditions.—In some literature the number and the value of Philippine mineral deposits have been overstated. Although mineral deposits of one kind or another have been found in all parts of the Archipelago and though mineralization is widespread, I am compelled, after ten years' intimate acquaint-

ance with the country, to say that very few already discovered deposits are of sufficient extent or richness to attract capital to undertake large-scale operations. The comparative geologic youth of most of the formations, the lack of persistence due to faulting and pinching, and the prevalence of archipelagic instead of continental conditions have affected the location, size, continuity, and value of the various deposits.

With such conditions, it behooves us to endeavor to make all the other circumstances affecting the industry's welfare as favorable as possible; that is to say, the inherent risk and difficulties are great enough, without human-made ones being added. In spite of the impression which the above statement may give, I am of the opinion that there are some excellent possibilities in the Philippine mineral field. The country has not yet been thoroughly prospected.

Personnel.—The personnel of the skilled force or of the superintendence is of vital importance in a country like the Philippines. The success of many a venture is assured or marred according to the personality and tact of managers, superintendents, and foremen. Only men of adaptability, pleasing personality, tact, and forbearance ought to be sent to the Islands to take charge of important mining operations. As soon as the effect of the climate begins to be shown, in manifestations of extreme irritability, the persons exhibiting such symptoms should be sent home and replaced by fresh men. Needless to say, young men of steady habits should be preferred. Persons with strong racial prejudice should, of course, be kept at home. Furthermore, the men selected for Philippine service should be carefully examined as to general health.

Many recommendations regarding living habits might be laid down; but one point must be emphasized here (not on moral grounds but as a purely economic measure) and that is that the habitual imbiber of alcoholics has no place in Philippine mining.

Hygiene.—In spite of all that has been written about health and climate in this country, many people will not learn from experience, and they find themselves and their undertakings sadly handicapped through neglect or oversight of matters pertaining to hygiene.

The only proper procedure for companies wishing to enter the Philippine field is to get complete instructions from the Bureau of Science before beginning permanent operations.

NONMETALLIC MINERALS

ABRASIVES

Stone mills for grinding corn by hand are manufactured in several provinces, although the value of the annual production of the industry is not great. Limestone is the material most widely used for millstones. Probably the best mills are made from an andesite from Rizal Province; in Ilocos Sur Province a calcareous sandstone is used. Certain schists, fine sandstones, and felsites are used in different parts of the Islands as whetstones for sharpening knives and bolos. The material for these whetstones is generally obtained locally, although a bluish green schist found near Lucena, Tayabas, is exported to neighboring towns and provinces.

A fine siliceous powder has been found on Panay, near Olongapo, Luzon, and at other places; it is very similar to the material known as tripoli, which is mined and sold in America for polishing and filtering purposes. This powder has been used locally for polishing brass.

ALUM

Alum incrustations are abundant around many volcanic vents. The commonest form is alunite, or alum stone. The Philippine deposits could be made to yield a considerable supply of this substance.*

ASBESTOS †

There was a very encouraging output of asbestos in 1919, but during 1920 mining operations on the old Dungon-Dungon estate in Ilocos Norte ceased, and so the production for that year is less than for the previous one. The Ilocos Asbestos Products Company evidently has found the undertaking too expensive for its limited capital. This company has a factory in Manila where it has turned out some valuable products in the nature of roofing material, pipe lagging, etc., and it is to be hoped that it will resume operations. The asbestos that has been mined has been largely of second and third grades, but some very fair specimens of chrysotile, as much as 2.5 centimeters in width, have been found.

For more than fifteen years the presence of asbestos in Ilocos Norte has been known. The district was first reported upon

* Alum can be prepared chemically much more cheaply perhaps than it can be mined locally.

† The section on Asbestos is contributed by Hubert G. Schenk.

geologically by Smith, in 1907.(558) After this date nothing more than brief mention of the district has appeared in the literature, with the result that little is known concerning the progress of asbestos mining in Ilocos Norte. I was detailed in March, 1921, to make an investigation of the asbestos property in the Dungon-Dungon district and to report on the progress of operations. At the time of the inspection, no asbestos was being mined.

Topography.—Many of the hills on the Dungon-Dungon estate are barren, except those capped by limestone, which always support vegetation. The slumped-off topography of serpentine areas is especially noticeable. This section of the country is maturely dissected, and Baruyen River apparently is a rejuvenated stream, as indicated by its many entrenched meanders. The coastal valleys are flat and fertile. Cape Bojeador, near Dungon-Dungon, is volcanic and decidedly wild and rugged.

Because of the topography, the roads in the district are hilly. At present, the roads on the Dungon-Dungon estate, which were not well constructed, are in very poor condition. They can be used by bull carts only, provided these carry no more than 150 to 200 kilograms as far as the main Government road, and then no more than 300 kilograms. During the rainy season the roads are impassable.

Bangui Bay is an open roadstead and not a satisfactory anchorage; although the waters may be calm to-day, the seas to-morrow may run high. The bay might be a safe harbor during the southwest monsoon. The nearest satisfactory port is that of Diriqui, 26 kilometers from Dungon-Dungon.

Geology.—The Dungon-Dungon district of Ilocos Norte is essentially one of metamorphism; namely, formation of schists, serpentinization, and amphibolization. Resting unconformably on the schists is limestone of Malumbang (Pliocene) age; Baruyen River has cut a deep cañon in this formation.

An idealized profile along a northwest-southeast line through Dungon-Dungon (fig. 19) shows the general field relations of the formations existing on the Dungon-Dungon property. There is no reliable map of the district.

Origin and occurrence of asbestos.—The asbestos on the property in the Dungon-Dungon district is thought to have been derived from pyroxenites, through processes of serpentinization and amphibolization, for both chrysotile veins and tremolite and actinolite veins are known to exist.

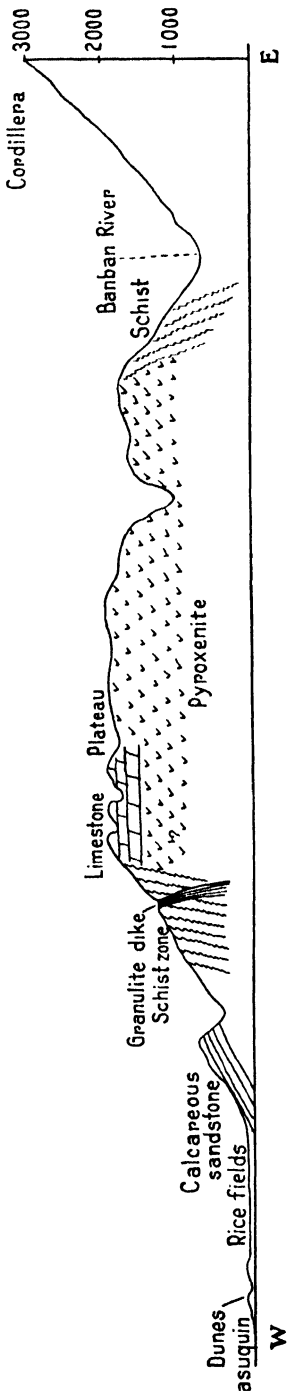


Fig. 19. Idealized geologic section from Pasuquin, Ilocos Norte Province, Luzon, northeast to cordillera.

Mining methods.—The mining of asbestos on the Ilocos Asbestos Products Company's property, near Dungon-Dungon, is entirely by open cuts, where the minerals occur in pockets or ramifying veins. The largest working—nothing more than a good prospect—is the Bed Creek mine, which has produced in the last two years 300 tons of asbestos. The Hill Top mine is the next largest; in the same period it has produced 50 tons of amphibole. Various scattered outcrops of serpentine have netted about 5 tons.

The material is loosened by hand and by blasting. The asbestos is chopped out by hand from the serpentine; waste is dumped by barrows; the fiber-bearing rock is placed in a shed, separated from its matrix by hand, and the fiber itself is placed in sacks (25 to 30 kilograms) or baskets. The sacks of fiber are carried by bull carts to Diriqui for shipment to Manila.

Amphibole is mined for about 20 pesos a ton. The cost of mining and cleaning chrysotile (crude extraction) in commercial quantity by this method would be extremely high, if not prohibitive. Transportation from the property of Diriqui amounts to from 7 to 9 pesos a ton; and from Diriqui to Manila the last shipment averaged about 22 pesos a ton.

It will be seen that the methods of mining are primitive and, in the long run, expensive. This company should have passed the prospecting stage some years ago and to-day should have some fairly well-developed mines.

Labor is cheap, but poor in quality. Up to 80 centavos a day is paid to the laborers and, in order to get sufficient help, women must be relied upon; according to Mr. Vittali, the manager, they are as good workers as the men. He also states that his experience shows the principal causes of the unreliability of the laborers to be lack of time for mining (most of them being small land owners) lack of endurance, and lack of regular application to work.

Transportation of the fiber is, as has been mentioned, by bull carts. A cart can make the trip to Diriqui in about two days. Travel on the Government road is difficult because of numerous and steep hills. There is plenty of good road metal in the vicinity, so that the construction of a good highway is possible.

Other localities.—Asbestos is reported to occur also in Zambales and in Antique. The Zambales deposit is near Subic, within the Army and Navy reservation. Samples submitted by prospectors are identified as amphibole and chrysotile. A detailed examination of the Antique deposit has not been made.

BITUMINOUS ROCK

The Leyte Asphalt and Mineral Oil Company, Ltd., reports that the 1920 production of bituminous limestone was approximately 2,000 tons, valued at about 30,000 pesos. Of this amount, 1,350 tons were shipped to the Philippine Government at Manila and Cebu, while about 20 tons were sent as samples to Australia and Japan. The past year saw considerable exploration and improvement work on the properties near Baliti, Leyte. The company has under construction a new pier, and has completed two new gravity inclines as well as some new roads between the Lucio mine and the new wharf. The increase in production of 600 tons since 1919 is encouraging. This material has been used with success on the streets of the city of Cebu and of Tokio, Japan.

CEMENT

The Rizal Cement Company, at Binañgonan on Laguna de Bay, which produced about 10,000 barrels of cement in 1919, failed. The failure was probably due to the overlooking of some vital factors in the manufacture of this article. A more favorable locality than Binañgonan has been found by a geologist of the Bureau of Science, at Naga, Cebu, and a contract has been let by the National Development Company to the Cebu Portland Cement Company.

There are other localities where cement materials are available. Batan Island in many ways is very favorably situated;

but, considering market, labor, coal, and transportation, Cebu appears to be somewhat better favored than the former. This subject has received exhaustive treatment in an article by Pratt.(487)

CLAY AND CLAY PRODUCTS

The manufacture of clay products in the Philippines is in a very backward state, due to two causes particularly; namely, proximity to the Chinese and Japanese centers of production and lack of skilled workers in the Philippines.

The only two Government agencies ever to make serious attempts to do anything toward introducing new methods and ideas into this line of manufacture are the Bureau of Education, through its School of Arts and Trades in Manila, and the Bureau of Science, by its chemical investigations.

I am indebted to Mr. C. H. Crowe, former head of the ceramic department of the Manila Trade School, for the following excerpts from an early article:(171)

> The pottery industry in the Philippine Islands is in a primitive state. Clay is not refined nor is any effort made to produce a superior product. Outside of Manila, with few exceptions, no kilns are used and no Filipino has heretofore made glazed ware. In various parts of the Philippine Islands there are good clays for all classes of clay products. There are deposits of fire clay needed in kiln construction and deposits of quartz and feldspar for the glazes. It is only necessary to interest the people and to educate young men who will be able to organize small factories and gradually develop the clay-working industry.
>
> In the 1912 Philippine Exposition, 12 provinces exhibited pottery and 10 of these had samples of clays. One province only, Laguna, had glazed ware. This was made in the towns of San Pedro Macati and Pagsanjan. The San Pedro Macati exhibit consisted of glazed flowerpots, fruit stands, pitchers, toys, etc. The body was yellowish and well-fired. The glaze was a lead silica mixture. Several of the pieces were pleasingly colored by the addition of metallic oxides to the glaze.
>
> The Pagsanjan factory is interesting from the fact that it was organized and managed by two boys who studied nine months in the pottery school of the Bureau of Education. They made their own bricks and built the kiln. They refined the clay, composed the glazes, and did all the work. They exhibited flower pots, water jars, pitchers, trays, toys, etc. The bodies of many pieces were red, but some of them were white. No Filipino has heretofore been able to use a white clay in pottery. These boys used a soft lead glaze in yellow, brown, green, and blue. This refining of clay, applying glazes, and firing in kilns marks a step in the advancement of clay work. Before the Bureau of Education instituted a pottery school, nothing but a crude, half-baked, unglazed ware was produced by any Filipino.

The work done by the Bureau of Science has been very fragmentary indeed, and to-day there is no complete study of this

subject. Cox (150) has contributed one or two papers, the principal being on the clays from Luzon. This and other work has been summarized by Witt.(645) This investigator was in search particularly of clays suitable for making vitrified paving brick, but most of the samples tested gave only fair results. Tests of a considerable variety of mixtures were made, but in nearly all cases the range of vitrification was too short and they were not suitable. Some of the Los Baños clays are suitable for fire brick.

Distribution of clays.—Of the four types of clay deposits, residual, colluvial, transported, and chemical, the residual and transported are the most abundant in the Philippines, apparently. Of the first type the lateritic deposits as ferruginous clays are, naturally, very widespread in a region of volcanism and extensive weathering like the Philippines. Some of the clays are so high in iron as to become valuable as iron ores. In certain districts, notably near Los Baños, Laguna, there are kaolin deposits which might be of future value.

However, the most widespread clay in the Philippines is a sort of adobe, usually the result of the weathering of basic igneous rocks, such as andesite and basalt or the sedimentaries derived from them. It may be of marine, lacustrine, flood plain, or estuarine origin.

Some of the most important clay samples in the Bureau of Science geologic collections have been listed by Witt, and his table is here presented as Table 28.

COAL

Coal and coke are needed in the Philippines for making steam, for cooking, for smithing, and for the manufacture of cooking gas and producer gas. The annual domestic production of coal amounts to 60,000 tons, approximately, and a larger amount is being imported. In 1920 imports, from Japan, Australia, and China principally, amounted to 531,550 tons. Until the entrance of the United States into the World War, coal production in the Philippines had nowhere been conducted very successfully over any considerable period. War conditions gave coal mining in these Islands a great impetus, and under favorable conditions it may remain an established industry. With the manufacture of iron and steel from the large deposits of iron that are known to exist in the Philippines, which may be soon undertaken, there will be given an added stimulus to the coal business.

TABLE 28.—*Samples of clays and shales in the Bureau of Science geologic collection.*

[This includes only those which are plastic and which contain no carbonates.]

Location of deposit.		Material.	Appearance of raw-clay test pieces.	Probable value.
Town and province.	Additional information.			
Batan, Batan Island	Entry No. 2, Bett's claim between coal seams.	Shale	Gray	Very good; vitrified below cone 7.
San Jose, Camarines	River north of Sabang.	do	Light brown, no strength.	
Culasi, Antique	Maralison Island	Kaolin	Gray, no strength.	
Antique Province		do	do	
Los Baños, Laguna		do	White, no strength.	
Angat, Bulacan	Maon Creek, pyrite veins	Clay	Gray	Fair; did not vitrify below cone 7.
Do	Mayapo	do	White, no strength.	
Surigao Province	Eugenio's house	Shale	Brown	Fair; did not vitrify below cone 7.
Isabela Province	Cagayan Nuevo mine	Clay	White, no strength.	
Tagonton, Camarines	San Mauricio mine	Kaolin	do	
Magalang, Pampanga	San Agustin	Clay	do	
Paracale, Camarines	Trinidad mine	Kaolin	Light brown, no strength.	
Nagcarlang, Laguna		Clay	Light brown	Possible; did not vitrify below cone 7.
Bucay, Abra		Kaolin	White, little strength.	
Mindoro Province		Clay	Light brown, little strength.	
Batac, Ilocos Norte		do	do	
La Union Province	Cruz Mountains	Shale	Brown	Fair; vitrified below cone 7.
Nasugbu, Batangas	East of town	Clay	White, no strength.	
Matiquio, Laguna		do	Light gray, little strength.	
Alfonso XIII, Palawan	Balabac Island	do	Reddish brown	Fair; did not vitrify below cone 7.
Manito, Albay		do	Gray	Possible; did not vitrify below cone 7.

Magpog, Mindoro		Kaolin	White, little strength.	
Los Baños, Laguna	Alpha mine	Clay	do	
Santa Mesa, Rizal	Pasig River	do	Gray	Very good; vitrified below cone 7.
Bulalacao, Mindoro	Mahohao River	Shale	Very dark gray	Very good.
Bannangan, Benguet	First hills on road to Baguio	Clay	Light brown, little strength.	
Los Baños, Laguna		Kaolin	do	
San Remigio, Antique		Clay	Gray	Very good; fu ed below cone 7.
Compostela, Cebu	Cotcot River	Shale	Brown	Fair; did not vitrify below cone 7.
Tiwi, Albay	Tigaboc	Kaolin	White, no strength.	
Bataan Province	Trail between San Jose and Mariveles; elevation, 106 meters	Clay	Gray, little strength.	
Cebu Province	Near Baliana	Shale	do	Possible.
San Fernando, Capiz, Sibuyan	Mabolo	Kaolin	Gray, no strength.	
Los Baños, Laguna		Clay	White, no strength.	
Baguio, Mountain	Kelly's mine	do	Gray, little strength	Possible.
Bamaoto, Sabagan, Mountain	Outcrop along trail	Shale	Gray, fair strength	Fair.
Placer, Surigao	Lagondola	Kaolin	White, very good strength.	

There is some coal on practically every large island of the Archipelago, but there are six localities of first importance; namely, Batan Island; Gotas-Butong, Dumanquilas Bay, Mindanao; Cebu Island; Polillo Island; Mindoro Island; and Masbate Island.

BATAN (554)

Batan Island is 15 kilometers, almost due east, from Legaspi, in Albay Province, which in turn is a part of the long irregular arm of southeastern Luzon. The island is from 15 to 20 kilometers long and 8 to 10 wide. It has an irregular coast line and, for its small size, is very mountainous; one peak attains an elevation of approximately 500 meters.

The formations are an igneous base of diorite; some serpentinized intrusives; the remnants of an iron formation; coal measures, including shales, sandstone, and coal seams; and at least two horizons of limestone, the upper one of which is rather coralliferous (Malumbang Pliocene)—in fact, it is quite probable that a coral limestone covered the entire island at an earlier time. The coal beds are inclined at various angles, often steep, and in some cases vertical. At the points where they can be most easily reached from the seashore the beds unfortunately dip into the island, thus necessitating hoisting and pumping. At eastern Batan there is a local down-faulted block of coal which has a slight dip to the sea. It is this block of coal that is being mined by the Philippine Coal Mining Company. There are at least two good seams of over 1.5 meters, and one or two more of uncertain thickness, which can be easily reached, almost at sea level.

From 1904 to 1910 the United States Army attempted to open and operate a coal mine on the west end of this island, at the sitio of Liguan; but, owing to difficulties, partly geologic and partly of a business nature, success was not attained and the then Secretary of War, Jacob M. Dickinson, closed the mine in 1910. A private enterprise has recently renewed operations in this locality. The coal at Liguan is, as will be seen from an inspection of Table 29, superior to most Philippine coals. It is greatly to be regretted that this mine did not prove a success in its initial undertaking.

The old Minas de Batan properties on the northeastern portion of the island (Calanaga Bay) were abandoned years ago. For several years a Spanish company employing Japanese miners, who used rather crude and wasteful methods, operated these properties, but the production never amounted to much.

On the east end of the island, near the old barrio of Batan, there have been several attempts at mining since 1907 with more or less success; and to-day, after several ups and downs, the Philippine Coal Mining Company is operating there successfully and producing between 200 and 400 tons per day, which is the largest production in the history of coal mining in the Philippines. The output is by no means steady, as it depends upon a fluctuating demand.

As yet not much trouble from gas in the mines has been experienced, and naked lights can be used, in spite of the fact that the coal is rich in volatile matter. In places, especially in eastern Batan, the coal contains considerable resin and sulphur. There is also some iron pyrites in the shale just above and below the coal, which causes the coal to take fire if it is not thoroughly cleaned or if it is allowed to stay too long on the dump. In 1905 I visited the old Bilbao property, on the north side of Batan Island; at that time the tunnels were abandoned because of spontaneous combustion in the workings. These points are mentioned in detail, not to present too discouraging an outlook, but so that investors and engineers may not enter the field with high expectations which experience with the facts will prove unfounded.

Batan Island is well situated, being directly in the track of steamers coming from San Francisco by way of Guam, the most direct route to Manila. A coaling station here would save the Army transports the long northward trip to Japan, where they now go to coal. On the other hand, it is off the track of many of the interisland trading vessels and large European tramp ships that touch at Cebu, Iloilo, and Manila.

CEBU (11, 561)

Coal in the Philippines was discovered in 1827 on Cebu.(113) Cebu is the second district in importance in the coal industry; although the mines located on this island are not the largest, there are more of them and the coal reserve there is greater than on Batan. Cebu is a long, narrow, mountainous island, with no navigable rivers, few bays, and but little wide coastal plain.

Geologically, many of the formations on Cebu are similar to those on Batan; there are also crystalline schists, volcanic flows, and old slates, all of which may yet be found on Batan, however. In two respects Cebu differs greatly from Batan. It is badly

deforested, as compared with Batan, and there is over the greater portion of Cebu a thick mantle of coral limestone, which has been cut through here and there by erosion, revealing the coal measures below. The coal measures are of the same age as those of Batan. Structurally, the island is badly faulted and there is more or less intense folding of the rocks, which makes coal mining difficult.

Scores of outcrops are known in at least fifteen localities, which are distributed from one end of the island to the other. The chief localities to which attention was paid by the Spaniards are to-day receiving the attention of Americans. All but one of these localities are on the eastern side of the central cordillera.

In the early days a great many claims were staked out in this field, but only a few were ever patented. At the present time, it is necessary to secure leases from the Government, as patents on freeholds are no longer issued.

Cebu is the headquarters of the National Coal Company, which has workings in the vicinity of Mount Licos, 15 kilometers west of Compostela, the site of rather extensive workings in Spanish times. To date this mine has not been particularly successful. In reality, the only property which approaches a real mine is that of the Mount Uling Coal Mining Company, situated about 12 kilometers west of Naga.

Cebu has the distinction of being the one island, in addition to Mindanao, where coking coal is known to exist. A seam about half a meter in thickness occurs at Guila-Guila, on Manangа River, about 5 kilometers west of the city of Cebu, on the property of Mr. Eugene Mitkievicz. There is also some coking coal at Mount Uling and on Toledo River.

Four principal coal seams which, more or less modified, can be identified in several localities, are known on this island and at Mount Licos; they were given in Spanish times the following names:

4. Pilarica.—1.4 meters; strike north 23° east, dip 30° southeast; 40-meter interval.
3. Enrique Abella.—1.2 to 1.5 meters; strike north 23° east, dip 40° southeast; 9-meter interval.
2. Esperanza.—50 centimeters; strike and dip same as No. 1; 40-meter interval.
1. Carmen.—1.6 meters thick; strike northeast and southwest, dip 30° southeast. This is the lowest.

Some small undertakings for the exploitation of coal at Mount Uling, Mount Licos, and Camansi were in progress prior to

1898, and a large project with Government backing was in process of formation just at the outbreak of the insurrection in 1896. This project was to have been under the supervision of Abella, the then Inspector de Minas of the Spanish Government, one of the ablest of the Spanish engineers in the Philippines and certainly the most competent geologist.

The property of the Danao Coal Mines, Limited, located at Camansi, Cebu, which mined several thousand tons in 1920, has recently been taken over by a large syndicate of foreigners in China, and it is expected that they will carry forward the work on a large scale. The seams in this field are continuations in part of those at Licos and of the field to the north.

In the field adjoining on the north known as Cajumay-jumayan, careful estimates by the late Benjamin Smith Lyman, a famous American coal engineer, who examined it in 1907, gave the workable coal reserve as at least 7,000,000 tons. In this field the coal seams lie in a syncline; elsewhere in Cebu they are generally in a monoclinal attitude.

SIBUGUEY PENINSULA, MINDANAO

The Sibuguey Peninsula coal field is perhaps experiencing the greatest amount of development of any of those named, as the principal holdings of the National Coal Company are located there. Coal is known in many places on this peninsula. The principal sites are Gotas, on the headwaters of Siay River, 4 kilometers west of Butong; Butong, about 12 kilometers from the town of Malangas; and Camp Wilmot, about halfway between Butong and Malangas, on Dumanquilas Bay. Along a line running across the peninsula from Malangas to Sibuguey Bay scores of coal outcrops can be seen.

The most extensive report on this region is a manuscript report by Dalburg. I recently made an investigation of the properties on this peninsula at the request of ex-Governor-General Harrison and, later, of Governor-General Wood, but my work covered principally the business aspects of the operations. Therefore, the following description is based in part upon Dalburg's report, and is supplemented by my recent observations.

The most important districts are Butong and Gotas (Plate 36). Butong is first on account of the railroad line nearing completion to that point, which will assure means of transportation; Gotas is second in importance on account of having a

fairly large body of coking coal. There is a possibility that the best part of the coal field lies just north of Gotas and Butong, which can only be proved by underground development.

The coal-bed sections show that there are at least three coal beds of sufficient thickness to be mined. At Butong, the main seam (semianthracite) is over 2 meters thick. The principal seam of coal at Butong is a semianthracite (see Table 29), which owes its high fixed-carbon content to local metamorphism by dikes and sills of andesite and basalt. A characteristic physical feature of this coal is the crystallization resulting in columnar jointing.

The physical and chemical properties of the coals are such as to make them suitable for fuel; they could be used instead of foreign coals and could compete favorably with them. The coal from the Butong seam is too hard to be used alone, without forced draft, and should be mixed with other coal.

Geologic conditions are such as to render mining somewhat difficult, but it is probable that some of the seams are of sufficient extent to allow of successful mining. Diamond drilling during the last year has proved that there is a fine body of coal in the vicinity of Butong. The main shaft for all the mines will be located in a basin to the east of the present exploratory shaft at Butong. The development of this field has not been altogether without mistakes, and some expenditures were made here before they were justified; but it is expected that the mining operations at present in progress will go forward now and produce better results.

At the time of my last visit to this mine (December, 1921) the work in the Butong district was progressing favorably, and a good thickness of coal, in excess of 2 meters, continues. The development work at Gotas has not been pushed, owing to lack of rail facilities, though this work may later be resumed. At Camp Wilmot there is a small production, and development work continues. The work in the Sibuguey field is under the very able superintendence of Mr. Caldwell, an English mining engineer, who had had five years of coal-mining experience at the Silompopum mine in British North Borneo before coming to the Philippines.

POLILLO

Polillo lies off the east coast of Luzon, about due east of Manila, is about 50 kilometers long by 25 kilometers wide, and is separated from the mainland by a channel 30 kilometers in width. This coast of Luzon is very sparsely settled.

The principal coal field lies a few kilometers inshore from the town of Burdeos in the eastern central part of the island, on Burdeos and Aloeon Creeks. The central part of the island is igneous, with granitic rocks resembling diorite, and on the flanks of the igneous complex are Tertiary sediments, with conglomerate, sandstone, shales, and limestone, in the order named, from below upward. Practically the same series of formations occurs here as in the other coal fields of the Islands. Structurally, there is one well-marked anticline and syncline with two monoclines, with the general axis north 20° west. Moderate and perhaps major faulting is in evidence. The age of the coal is middle Miocene. There are three well-developed coal seams; respectively, 1.5 meters, 0.6 meter, and 1.2 meters in thickness; others are too small to be worked. The principal coal seam is the Wray seam. It was named for its discoverer, Captain Wray, formerly of the Philippine Scouts. There is no development or mining on Polillo at present (June, 1921). Formerly, there was some prospecting work at the so-called Wray mine, on Guinibauan Creek. The following is a copy of notes made by me while on the ground on my last visit in 1910. As there has been practically no work since, these notes are up to date:

Quality of coal at the Wray mine.—Upper portion, shiny black, powder black, lower portion dull, brownish black, resembling "bone;" fine, angular, shiny particles cemented in a coaly matrix. Fairly free from clay or sand; 2 to 2.5 centimeters sooty clay parting between the two portions. No sulphur visible, some gypsum. Fairly firm for outcrop coal, lower part of seam exceedingly hard and firm. It is reported that this coal does not air slack. A large lump that has been in the division of mines for five years has not slacked at all. (At present, seven or eight years later, it is still firm and solid.) No well-defined cleats; slickensides or shear surfaces characteristic. Does not coke. Good steaming coal. The coal field is bounded definitely on the west by volcanic rock. The coal beds do not appear to be continuous in a north and south direction; witness the almost entire absence of outcrops in the north branch of Guinibauan Creek. The seams are flattening toward the coast, and will be found there in all probability of inferior grade to the more highly inclined seams to the west.

The folding in this region was due to lateral thrust against an abutment of resistant rock, the igneous complex in the center of the island. There are no indications of intrusions.

Given continuous seams, which will have to be proved by more excavations, there is nothing prohibitive in the geology. Mining operations will, however, not be simple.

This coal, it can be seen, is of very fair grade. The chief factor that militates against it as a commercial proposition is

the geographic situation of the island, as it is well off the track of interisland steamers. Some years ago there was much talk about developing a port for Manila on the east coast of Luzon, just opposite Polillo Island. This, of course, would have boomed Polillo coal. The project, however, has never advanced beyond that stage. The field was examined some years ago by Mr. J. B. Dilworth, of Philadelphia, then in the employ of the well-known American coal expert, D'Invilliers; in an article on Philippine coal fields,(191) in 1908, he had this to say on Polillo coal:

> All practical and laboratory tests of this coal show it to rank in quality with the best in the Philippines. It is the equal chemically of that from western Batan, and is but little inferior to the Japanese fuel now on the market. But in this field, as in western Batan, geologic disturbances have rendered the coal seams structurally difficult to mine economically on a large scale.

MASBATE

At two places on Masbate fair coal seams have been found. These are near Cataingan and Dimas-Alang, near the lower end of the eastern prong of the island. The deposits have been known for a long time, and some attempts to mine coal there were made in Spanish times, particularly on the old Spanish concession containing two *pertenencias* known as the San Jose and the Santa Cruz.

There are practically no published data with reference to these deposits, but in 1910 Ferguson made a private report from which I have taken some very general notes. The reader will understand that this report was not meant for publication, and Mr. Ferguson has not since examined the region nor had a chance to make any changes in the report as originally submitted. Therefore, I alone am responsible for the following interpretation of his statements. In as much as I later visited a portion of this field I am in a position to substantiate Ferguson's statements of fact and of opinion.

The principal deposits are located near the barrio of Nabangig. It was Ferguson's opinion that there are three main workable seams of coal in that locality. The three workable seams are each approximately a meter in thickness, and they dip very steeply to the northeast, though there are some local departures from this. The coal measures are comparatively closely folded, with one well-marked anticline and syncline. Some faulting was noted, but the most serious feature of the field in the places examined by me was the lack of persistence, the coal

thickening and thinning within short distances, in some places disappearing entirely, due either to pinching or to faulting.

Ferguson considered the coal to be of good quality. Some coking coal was noted by him at Dimas-Alang, but for several reasons was considered valueless. No work has been done in that region since the prospecting work which called for the report made by Ferguson. An analysis of the coal from one of the best seams is given in Table 29.

Transportation to a shipping point might be provided by a tramline about 15 kilometers in length through country which, according to Ferguson, offers no considerable topographic difficulties. Port Cataingan, he thought, would be the natural outlet for this coal. Good timber in sufficient quantity is found in this region. Labor is moderately cheap when available, though the gold mines in the Aroroy district absorb most of the local supply. The geographic situation appears to be the chief favorable feature of this field.

MINDORO

At the southern end of Mindoro, near Bulalacao, are some deposits of coal of medium grade which have long been known and where some development work was done in Spanish times. I visited this locality in 1910, but was unfavorably impressed with both the conditions and the quality of the coal.

The thickest seam of coal is 7 or 8 kilometers up Bulalacao River. It is 4 meters (approximately) in width. An analysis of coal from this field (not from this particular seam), is given in Table 29. Early reports mention at least six seams, but I doubt that there are more than three or four that are workable.

On Semirara, a small island directly south of Mindoro, there are also coal seams, undoubtedly the continuation of those near Bulalacao. About the year 1893, title was issued for a mine on Semirara, but I know nothing of its development. The Recoletos Fathers also had some coal properties there, but apparently nothing was ever done to develop them.

Coal deposits of seemingly commercial possibilities, in the following five localities, have attracted attention from time to time; they will merely be listed here, but the interested reader can find some reference to practically all of them in Burritt's Coal Measures of the Philippines.(113) These are Alabat Island, off the north coast of Tayabas, Luzon; Dinagat Island, off the north coast of Surigao, Mindanao; Escalante, on the northeast coast of Negros; Catanduanes, north of Batan Island, off the

east coast of Luzon; and Gatbo, Sugod Bay, Sorsogon Province, southeastern Luzon.

CHEMICAL AND PHYSICAL CHARACTERS OF PHILIPPINE COAL(163)

Philippine coal is of three chief classes; namely, semianthracite (hard coal), subbituminous (black coal), and lignite (black and brown coal). The following data with reference to the character of Philippine coal are taken from notes by Dalburg, with some revisions:

Much of the lignite coal is black and very seldom shows a woody structure or brown color. The coals that slack or crumble on exposure to the air break with an irregular fracture, which as a rule does not conform to the bedding planes or cleats.

The lignites are found where the rocks are little disturbed and away from the lines of uplift. The subbituminous and bituminous coals occur near the bases of mountains or where the lateral disturbances and pressure which folded the formation have made a great change in the character of the coal.

Philippine coals are generally noncoking, although fair coking coals have been found at Gotas, Mindanao, and Guila-Guila, Mount Uling, and Toledo, Cebu.

The coal will generally stow about 48 cubic feet to the ton. It is friable, and a large percentage is small or broken. Unless carefully fired a portion only is consumed and the rest goes through the grate bars. In some cases the ashes may be fired twice and still contain a considerable amount of combustible. An important question is the proper spacing of the grate bars which should not be over 0.75 inch apart. The coal is very gaseous, and it is almost impossible to insure complete combustion in an ordinary type of boiler furnace. Firing lightly and almost continuously insures the best results.

Recent tests on a German gas producer have shown the coal to be suitable for this purpose.

Considerable difficulty is experienced in storing the lignite coals, due to spontaneous combustion.

The fuel value of the best Philippine coals is from two-thirds to three-fourths that of the best Cardiff coals and very little short of that of the Borneo and Japanese coals.

Table 29 gives the analyses of representative Philippine coals.

These analyses were made by the "smoking off" method in which the coal is subjected to a low heat so as to expel the volatile matter with a very small flame and finally heated for seven minutes over a Bunsen burner.

TABLE 29.—*Analyses of Philippine coals.*

[Analyses from the Bureau of Science, Manila.]

Air-dried basis.	East Batan.	Liguan.	Calanaga.	Camujumayan.	Camansi.	Mount Licos.	Uling.	Bulalacao.	Cataingan.	Polillo.	Sibuguey.	
											Butong.	Gotas.
Proximate analysis:												
Moisture	18.32	5.81	13.28	12.49	7.49	8 10	14 90	17.57	4 87	3 76	2.05	1.25
Volatile matter	36.53	39 39	39.10	41.63	44.18	40.73	38.63	42.43	46.50	43.58	12.95	18.57
Fixed carbon	36 60	49.71	39.13	42.41	43.90	48 21	41 91	31 49	44.18	38.60	75.60	73.72
Ash	8.55	5.09	8.49	3.47	4.43	2 96	4.56	8 51	4 45	4 06	9 40	6.46
Ultimate analysis:												
Sulphur	1.02	0.12	1 93	0.65	2.40	0.42	0 35	2.54		0.32	0 71	0 71
Hydrogen	5.32	5.08	11		5.11	5.72		5 87		5.54		
Carbon	51 55	68.14			66 18	66 46		52.60		70.47		
Nitrogen	0.92	1.11		1.64	1.72	2.10		0 96		1 59		
Oxygen	32.64	20 56			20 16	22.34		29 52		18 02		
Calorific value determined:												
Calories	4,618	6,358	5,221	5,761	6,249	6,424		4,959		6,775	7,730	7,730
British thermal units	8,312	11,444	9,398	10,370	11,284	11,563		8,926		12,195	13,775	13,914
Calorific value calculated from ultimate analysis:												
Calories	4,603	6,386	5,266		6,294	6,389		5,058		6,840		
British thermal units	8,285	11,495	9,479		11,329	11,500		9,104		12,312		

The sampling was done according to the Bureau of Science method, which is practically the same as that of the United States Bureau of Mines.

The results are given on an air-dried basis, at laboratory temperature (30° C.).

COAL SEAMS AND INCLOSING BEDS

In general, there are four workable seams in most of the fields, though in practically each only one seam is being mined. Some of the drill records show more than four present in some localities.

On the United States Army Mine Reservation near Liguan, Batan Island, drill hole 4A, beginning at about 200 feet elevation, gave the following record of the strata:

TABLE 30.—*Strata from drill hole 4A on Batan Island; from above downward.*

	Material.	Feet.
	Shale	20
	Grit (coarse SS)	8
1.	Coal	3
	Shale	10
	Grit	10
	Shale	5
	Grit	24
	Shale	
2.	Coal	2.5
	Coarse SS	10
3.	Coal	2
	Shale	30
4.	Coal	6
	Shale	2
5.	Coal	1
	Shale	1
6.	Coal	1
	Coarse SS	10
7.	Coal	4
	Shale	32
	SS (?)	
8.	Coal	5
	Shale	20
	Limestone, bottom of hole	15

An examination of these records which, I regret to say, are not altogether accurate, reveals several important facts; namely, (*a*) that there are at least eight seams of coal on this part of Batan Island, four of which are workable; (*b*) that these beds are not persistent; and (*c*) that shale forms the floor and coarse gritty sandstone the roof.

Drill records from borings on the property of the National Coal Company at Butong, Sibuguey Péninsula, show the presence of sills of igneous rock intercalated with coal measures, which may account for the anthracitization of the coal in this locality. One of these sills is very persistent and is found in the same relation to the chief coal seam in several of the borings. The following is a copy of the record of bore hole 4:

TABLE 31.—*Record of bore hole 4, at Butong, Sibuguey coal field; from above downward.*

	Material.	Meters.
	Clay	
	Sandstone	
	Shale	
	Compact limestone	
	Basalt	
	Shale	
	Sandstone	
	Sandy shale	
	Shale	
	Compact limestone	
	Shale	
	Bone with coal parting	
	Shale	
1.	Coal	0.15
	Shale	
2.	Coal	0.15
	Shale	
3.	Coal	0.15
	Shale	
	Sandstone	
	Shale	
4.	Coal	1.98
	Shale	
5.	Coal	0.15
	Shale	
	Bone	
	Shale	
	Sandstone, bottom of hole.	

Hole began at an elevation of 108.5 meters.

A generalized section of the stratigraphy in the Cajumay-jumayan field, Cebu Island, made by the late Benjamin Smith Lyman, an eminent coal engineer, is as follows:

TABLE 32.—*Stratigraphy of the Cajumay-jumayan coal field, Cebu.*

Material.	Feet.	Inches.
Coralline limestone of unknown thickness, perhaps	500	
Unconformity		
Shales, sandrock and pebble rock? poorly, if at all, exposed, perhaps	1,200	

TABLE 32.—*Stratigraphy of the Cajumay-jumayan coal field, Cebu*—Continued.

Material.	Feet.	Inches.
G. Coal bed, including shales; average of the eight completest exposures	12	5
Shales, sand rock and pebble rock? poorly exposed	215	0+—
F. Coal bed, including very little slate, average of ten exposures	4	0
Shales, sand rock and pebble rock, poorly exposed	125	0+
E. Coal bed, including little slate, average of 4 exposures	3	0
Pebble rock, sand rock and shales, much exposed at the Hogback; probably not far from	650	
D. Coal bed, unworkable, without slate or shale, average of 3 exposures	1	6
Shales, sand rock and pebble rock, poorly fectly exposed	65	
C. Coal bed, including slate or shale, average of 6 exposures	7	5
Shales, sand rock and pebble rock, poorly exposed	70	
B. Coal bed, including little slate or shale, average of 7 exposures	11	
Shales, sand rock and pebble rock, partly exposed on Dunga Creek	130	0+
A. Coal bed without slate or shale, average of 2 exposures	7	7
Pebble rock, sand rock and shale, partly exposed on Dunga Creek and northwards, perhaps	800	
D. Sidra's unworkable coal	1	10
Shales and sand rock? poorly exposed, if at all	130	
Coal traces, 300 yards west of D. Sidra's		
Shales, sand rock and pebble rock? poorly exposed perhaps	500	
	3,936	9

Unconformity

Igneous rock rising to unknown heights, exposed, a little, southeast of Mount Lantauan and probably in the western part of the Boy Claim.

We have, then, say 4,000 feet of the coal bearing rocks hereabouts, with unconformable coralline limestone above and igneous rock below.

In each of the districts of Cebu there is a limestone horizon just above the coal measures and conformable with them, which is very characteristic and which can be used as a datum. This

limestone is very compact bluish to buff-colored rock containing myriads of large Foraminifera of the genus *Lepidocyclina*, of which *L. richthofeni* Smith and *L. insulae-natalis* Ch. are the commonest species.

In Mesaba Creek, barrio of Cantobaco, about 0.5 kilometer north of the Cebu-Toledo Road, on the coal land leased by Quintin Rivera and associates, there is a fine section which, roughly, is as follows:

TABLE 33.—*Section in Mesaba Creek, Cebu.*

	Meters.
Coarse, heavy bedded SS	20–30
Lepidocycline limestone	5–10
Sandy shale	1–2
Coal	0.3–0.6
Sandy shale	12–15
Coal	0.3–0.5
Sandy shale, bottom of section.	

At this place the strike is north 40° west and the dip 15° to 20° southwest.

On Catanduanes Island, which is about 30 kilometers north of Batan Island, there is coal which may be the continuation of one or more of the Batan seams, though it is more than likely that the coal on the several islands of the Philippine group were formed in separate basins.

We are indebted to Mr. E. H. Koert for the following section of the coal measures of that island:

TABLE 34.—*Section of coal measures on Catanduanes; from above downward.*

	Meters.
1. Sandstone containing marine fossils in lower portion	
2. Shale and "slate"	
3. Coal	5
4. Shaly sandstone, thin layer	
5. Coal	1
6. Blue-yellow clay, probably fire clay	
7. Iron ore	2–3
8. Tuff, blending into red shale, thickness not given	
9. Sandstone with conglomerate at bottom, thickness not given.	
10. Diabase, thickness not given.	

In some manuscript notes L. A. Faustino calls attention to the similarity between the Enriqueta seam at Mount Licos, Cebu (whose thickness of 1.2 meters and 5 to 7 centimeters shale parting about 45 centimeters from the roof is similar to the main seam at Camansi, Danao, Cebu) and another one in tunnel 14 at Gotas, Malangas, Mindanao, and the principal seam on East

Batan. Owing to the geologic conditions, one cannot be certain that these seams are to be correlated over such distances, but the similarity is suggestive.

GEOLOGIC FACTORS AFFECTING COAL MINING

Several geologic factors are of extreme practical importance in the mining of Philippine coal, and these are the lack of persistence of the coal, faulting, igneous intrusions and flows, amount of folding, and the age of the coal.

The lack of persistence of the coal seams in many localities has been commented upon by several persons who have studied Philippine coals. The pinching out of the seam just when one is driving ahead and counting on a certain definite and steady output is very disconcerting. Pratt has discussed this subject in a special paper, and I have alluded to it. It appears that the chief reason for such lack of persistence is the irregular deposition of sediment due to torrential precipitation which probably was the rule throughout the whole of Malaysia during the Tertiary, as it is to-day.

In many coal beds in the Philippines lack of persistence is due to a totally different cause; namely, faulting. However, once the system of faulting in a given district has been learned and the seam been relocated, it is usually found to persist, which is not the case in pinching. Faulting, on both a major and a minor scale, is found in almost every Philippine coal field. Throws ranging from only a few centimeters to hundreds of meters are known, and such faulting is going on at the present time. Some examples of thrust faulting on a minor scale are known, but most of the faults are normal. In the Uling coal field this condition is well shown where the Uling Coal Mining Company is mining a block of about 10,000 tons of coal that has dropped down and is practically separated from the rest of the field. The faults can be easily seen in the galleries.

At Licos the Esperanza and the Enrique Abella veins are faulted in No. 8 tunnel, where there is a displacement of 50 meters and a throw of 12 meters. The direction of this fault is north 65° east. In the old Montañes tunnel a fault was encountered with a throw of 25 meters. Faults of far greater magnitude on this island are indicated by the topography.

The influence of igneous rocks upon coal seams is well known. In the Philippines the coal seams have been intruded and disturbed perhaps more than is at present realized. At Butong, Sibuguey Peninsula, Mindanao, the coal measures have been

intruded by dikes and sills of igneous rocks, and in that field a semianthracite coal is found. In places completely recrystallized coal occurs, simulating the hexagonal jointing in basalt.

The degree of folding also is very important. Facts in support of this statement need not be reviewed, as they are learned by experience and are discussed in any good textbook. Perhaps nowhere in the Philippines can the effect of folding and the resultant changes be better seen than on Batan Island. On the west end of that island the formations are intensely disturbed, the coal strata being tilted at high angles and faulted as well. In all this crumpling the coal seams have been sheared in some places; in others they have cracked and opened. This has accelerated the process of distillation, which would ordinarily proceed slowly, and as a result the coal near Liguan has a higher percentage of fixed carbon than has the coal on the east end of Batan, where the seams are less strongly folded.

The age of the coal is very important also. It is a common saying among American prospectors that Philippine coal is "too green" to be any good, and this is not very far from the truth. Philippine coal is of Tertiary age, most of it having been formed in the Miocene period of that era, although it may yet be found that some of the lowermost seams are somewhat older. Usually Tertiary coal, no matter in what part of the world it is found, is inferior to coal of Cretaceous, Jurassic, or Carboniferous age.

Most Philippine coals are very similar to the Eocene and the Miocene coals of the West Coast of America, which in turn are decidedly inferior to the Cretaceous coal of British Columbia or the Carboniferous coal of eastern America.*

It is true, as already pointed out in connection with the Butong coal of Mindanao, that, owing to peculiar local conditions, a high grade of coal (in this case semianthracite) has resulted from the metamorphism of Tertiary coal.

It is obvious that four of the geologic factors named above have a profound influence upon the method and the cost of mining. This is well exemplified by the difference in system and cost of operating the mines on East Batan and those on Cebu. Usually, and fortunately so, the commercial value of coal seams is in direct proportion to the difficulty and expense of mining the coal.

* An exception to this statement has been noted by Doctor Kryshtafovich in the coals of Saghalien Island.

CONDITIONS AFFECTING THE MINING OF PHILIPPINE COAL

There are some factors of importance, aside from those discussed in earlier paragraphs, to be considered in the mining of Philippine coal; these are taxation, regulations, labor, and the paquiao system. Taxation is discussed on page 541.

The Philippine Government has in operation a coal-leasing law which in the main is very liberal and under which coal operators can work. The regulations accompanying the law have now been revised. In coal mining, which is the most difficult kind of mining, Filipino labor has done fairly well. Labor costs differ in the different districts. In general, capataces receive 50 to 75 pesos per month; miners, timberers, wagon men, and outside men, 1.10 to 1.60 pesos per day.

A very important factor in the economical production of coal in the Philippines is the so-called paquiao system, which seriously concerns the coal operator in two ways. In the first place, the paquiao system is a local contract system which is the crudest and most wasteful (a sort of "gophering" along outcrops) with which operators have to compete. Second, this system ruins much good coal-mining territory for future large-scale operations. I have been underground where new development work has run into these old "gopher holes" and have seen the damage, particularly in the rainy season, resulting from this pernicious system.

Steps have recently been taken to curtail some of this kind of mining, but a great deal of damage has already been done. The system has been in wide use on Cebu Island. There are scores of such coal-mining operations on that island now.

METHODS OF MINING

The common method of mining coal adopted by the larger operators in the Philippines is the "room and pillar" system, but in some of the mines the work follows no regular system. In the Philippine Coal Company mine, the seam is so nearly flat that it is very easy to lay out the work systematically and follow it out; but, when the seams become more and more highly inclined, as they do in Cebu, it is not so easy. In some of these properties a system like the "battery" would probably work better. In the flatter seams, like those on eastern Batan, the "long wall" might be the best method, but a bad roof is the chief objection there.

In the paquiao work the Filipino and Japanese laborers simply undercut an outcrop with small Japanese picks until they

are either driven out by water or bad air or until the ground caves. They do a certain amount of a poor sort of timbering, which consists merely of a few irregular props.

The larger mines, superintended by white men, are usually provided with good timbering and ventilation. As yet very little undercutting by machinery is employed and only a small amount of shooting coal is done. Many kinds of timber are used, but, owing to the hot and wet condition of most of the mines, *pagatpat*, or mangrove, a very durable wood, has been found the most serviceable.

Preparation of the coal for the market.—Modern coal-washing equipment has been installed only at Malangas, on the property of the National Coal Company. At Uling a very satisfactory coal-washing and screening apparatus of home manufacture has been used successfully for a year or so.

Market.—The entire output of Philippine coal mines is disposed of in the Philippines, the bulk of it being used by interisland merchant vessels. Some other local uses are found for it in operating hemp presses, roadrollers, ice plants, railroad locomotives, etc. That it could be more economically used to a greater degree than at present is indicated by the success attained by the Philippine Bureau of Science, where electric power has been produced by means of a 67-horsepower Otto suction producer-gas plant at 0.03 peso per net kilowatt hour (prewar figures).

An important consideration in placing Philippine coal on the market is transportation; this is either very poor or absolutely lacking in many localities where a fair grade of coal exists, and interisland freight rates are exorbitant.

There is no good reason, save high cost of labor, why almost all imported coal cannot be replaced by domestic coal.

TABLE 35.—*Minimum costs per ton of mining and marketing Philippine coal and Manila price of Chinese "slack" as of June, 1921.*

[Data furnished by a coal engineer.]

	Pesos.
Mining	3.00
Freight	5.00
Unloading and stock piling	2.00
Loss, about 10 per cent	1.00
Taxes	2.00
Total	13.00
Chinese "slack" from Tientsin now selling in Manila	16.00
Margin	3.00

As very few operators ever cut their mining costs to as low as 3 pesos it can readily be seen how small is the margin of profit in normal times. During the war period prices for local coal were inordinately high, owing to the cutting off of the foreign supply, and many persons have unwisely made plans based upon those figures. Needless to say, a rude awakening awaits them. In fact, coal prices have already dropped and they will continue to do so.

Conclusion.—In conclusion, it may be said with confidence that a good industry can be built up by developing Philippine coal deposits. There are adequate coal reserves, but there are many features which make the business a difficult one. The Filipinos are for the most part more given to agriculture than to mining at present, but the younger generation may take a hand in the mining industry.

CORUNDUM

Corundum pebbles have been found in the alluvials of Nueva Ecija Province. The probable quantity is not known. Corundum is an important constituent of emery.

GEMS AND PRECIOUS STONES

Specimens of agate, opal, and amethyst have been found in the Islands, indicating that valuable ornamental stones may be found here in quantity if diligent search is made for them.

GUANO AND PHOSPHATES

Guano occurs in limestone caves in nearly every province. Studies made by the Bureau of Science show the guano from many localities to be valuable for fertilizing purposes. An area of leucite-tephrite, a potash-bearing rock, which may at some time become a source of potash, has been discovered and mapped by the Bureau of Science. This rock occurs near Aroroy, Masbate. The mineral apatite, a calcium phosphate, is found in Ilocos Norte and is a possible source of phosphates.

Rock phosphate, consisting largely of tuffs and limestones that have been locally enriched by leaching from guano deposits, have been recently discovered in promising quantity near Dumarao and other points on Panay Island.

GYPSUM

Large specimens of gypsum have been received by the Bureau of Science from the barrio of Talahib near Loboo, Batangas Province, Luzon. It probably exists there in commercial quan-

tities. The occurrence of gypsum crystals has been often noted around volcanic fumaroles, from which a fair supply might be obtained.

LIME

Pure coralline and crystalline limestone, suitable for the manufacture of lime, occurs throughout the Philippine Islands. A considerable fraction of the rocks of the Islands consists of limestone, which is generally pure. The value of the lime produced is, normally, about 100,000 pesos per annum, and the production does not meet the demand in either quantity or quality; the objectionable quality is entirely due to the poor methods of manufacture employed. The production of sugar by modern methods is increasing the demand for lime.

MICA AND TALC

Undeveloped deposits of mica and talc exist in Ilocos Norte, Pampanga, and other provinces; they may prove to be of commercial value.

OCHER

Deposits of limonite have been worked in Ilocos Norte Province and, by burning, red and yellow ochers have been prepared which have found a limited market in Manila. Cheap red and yellow paints might be made from this material. Deposits of limonite undoubtedly exist in many parts of the Philippines.

PETROLEUM AND RESIDUAL BITUMENS *

Petroleum gives some promise of proving to be an asset. The drilling operations now in progress on Bondoc Peninsula, Tayabas Province, Luzon, are of great interest in this connection. Here the Richmond Petroleum Company, a subsidiary of the Standard Oil Company of California, is drilling on the most favorable-looking structure I have yet seen in the Archipelago. If its borings are not successful on this structure after three or four holes are put down, further boring in the Philippines would seem to be a doubtful venture. The first hole in which only a very slight "show" of oil or gas was obtained was abandoned at 400 meters (approximately) owing to caving. A second well on Amuguis No. 2 is now (July, 1922) over 800 meters deep. Some water and gas have been encountered but no oil.

* Much of the following information was taken from reports by Pratt, and I have been in all these fields.—W. D. S.

Petroleum seeps in the Philippines have been known for many years. In view of the presence of petroleum in commercial quantities in Borneo to the southwest, and Formosa (though in much smaller quantities) to the north, and the worldwide demand for petroleum and its products, great interest in the Philippines as a possible producer is natural. The result of the present operations of the Richmond Petroleum Company on Bondoc Peninsula is of more than local interest. Should a commercial supply of oil in the Philippine Islands be secured the effect upon political, military, and commercial problems will be profound.

The principal source of oil in the Philippines is the group of shales, with intercalated limestone beds, to which has been given the name Vigo, from the type locality on Vigo River in Bondoc Peninsula.

The typical oil shale on Bondoc Peninsula may be described, quoting from a report of Pratt and Smith,(506) as consisting—

> * * * of fine-grained shale and sandy shale interstratified in thin regular beds from 5 to 10 centimeters in thickness. Occasional beds of sandstone occur varying from 10 centimeters to 1 meter in thickness. The fine-grained shale is gray, blue, or black, and is made up almost entirely of clay. * * *
>
> The blue or black, fine-grained shale in the Vigo formation usually emits a slight odor of light oils upon fresh fracture, and in some outcrops is highly petroliferous. The material loses this odor and assumes a light gray color after it has been exposed to the air and has become thoroughly dry.

These shales contained numerous Foraminifera of the genus *Globigerina*, which may be the source of the oil. Although they are numerous, these organisms did not appear to comprise a large percentage of the volume of the shales. However, shales from Leyte and Mindanao contain them in large numbers.

The Vigo shales are found to be hundreds of meters in thickness in several parts of the Islands and much thinner in others. The age of the shales is middle Miocene; they are easily recognized by certain index fossils which have been determined by paleontologists. Some of the most characteristic are the round, globular protozoan, known as *Globigerina;* a small bivalve shell, *Corbula socialis;* a flat-topped cone shell, *Conus ornatissimus;* another gastropod, or snail, with a high spire and very much tuberculated, *Cerithium jenkinsi;* and a much-coiled cast of a worm borer, *Vermetus javanus.* These fossils are well known

in connection with the oil shales of Java. Specimens of them may be seen in the Bureau of Science collection.

The Canguinsa sandstone, a buff-colored, very porous, and somewhat tuffaceous formation above the Vigo, may prove to be the reservoir for holding the oil.

Structure.—It has long been known that an important condition for the accumulation of commercial supplies of oil is the anticline, or arched flexure, of the rock strata. In southern Sumatra, according to one authority, no oil has been obtained in commercial supplies except by boring on the crests of these anticlines. The double flexure, where the anticline plunges at both ends, forming a dome, affords ideal conditions. By no means all of the productive wells in the world are located on anticlines, but in new country it is desirable to locate the most favorable structures for "wild-catting."

Location of prospects.—The chief seeps and most promising prospects are located as follows: Bondoc Peninsula (lower end), Tayabas Province, southeastern Luzon; the ozocerite veins near Villaba and the asphaltic tuff near Baliti, both in the northwestern part of Leyte; Pidatan district, in central Mindanao; the west coast of Cebu, from Alegria north, to and perhaps beyond Toledo; natural gas from some deep wells in Tertiary shale on the eastern flank of the cordillera and the low country to the east on Panay. Other seeps have been reported from the southern end of Mindoro and from Siasi Island.

All the known oil seeps, petroleum residues, and natural-gas emanations in the Philippines are associated with Tertiary or later sediments.

Special localities.—In Bondoc Peninsula, the seeps are in highly inclined strata which are probably in all cases part of anticlinal and fault structures. From this association it is believed that the petroleum in this field has, in accordance with the general law of petroleum accumulation, tended to collect in the crests of anticlines.

The petroleum occurs, associated with certain horizons, in an extensive series of beds of sandstone and shale (Vigo shale), which is similar in character to the oil-bearing rocks of productive fields, notably those of Japan. The principal seeps are found in the upper part of this series in a zone designated by Pratt as the Bacau stage, which is predominantly shale but which contains subordinate beds of sandstone. In its seepage, the petroleum is associated with the shale rather than with the

sandstone, and may be observed in some cases to come directly from the shale. Beneath the surface, where closed lenses of sandstone probably exist, one would expect to find the principal accumulation of petroleum in the more open, sandy zones. At the surface the light oil appears to have escaped readily from the coarse-grained beds, and to have been retained only in the fine-grained shale.

The structure of Bondoc Peninsula includes a number of anticlinal folds; the conditions along some of these anticlines are considered favorable for the accumulation and retention of petroleum, whether it occurs in all or in any one of the horizons at which it is suspected to occur.

The localities enumerated below are considered some of the more promising as sites for the location of "wild-cat" wells in exploring the petroleum-bearing rocks of Bondoc Peninsula. However, owing to conditions discussed in Pratt and Smith's report, cited above, it is possible that oil may be encountered at any one of the sites, even though it be absent elsewhere. There are many places other than those listed which would be considered as favorable in case exploration of any of the sites herein recommended prove successful.

1. The Maglihi anticline in the southeastern part of the peninsula, near Mount Morabi.

2. The Maglihi anticline in the valley of Bahay River.

3. The central anticline in the vicinity of Balinsog or Bacau. Recent work shows that earlier reports of the structure of this need modification; parts do not appear to be altogether suitable. The Richmond Petroleum Company of California has drilled one hole to a depth of about 400 meters, which caved, on the Amuguis anticline just south of the central anticline. The rig has been moved about 3 kilometers farther north, higher on the structure, and the hole is now over 800 meters deep without any results (July, 1922).

4. The Ayoni anticline, about 1,500 meters inland from the mouth of Ayoni River on the west coast.

5. The Malipa anticline, near Cabongahan.

LEYTE

It has been known since 1890, at least, that petroleum existed near Villaba, Leyte.

Rock "asphalt" was discovered in 1913 by a Filipino forest ranger, and a period of active claim staking followed. Not until 1918, however, was the deposit opened commercially.

The extreme northwestern peninsular portion of Leyte, as far south as Baliti, is worthy of careful exploration. The geologic formations here, according to Pratt,(494) are a continuation of those on Bondoc Peninsula.

Petroleum is encountered at two places in Leyte; it seeps from the upturned edges of the Vigo shale, and oozes from the base of a hill which consists of a clayey tuff-sandstone belonging to the Canguinsa. Residual bitumens occur in the Canguinsa and in the Malumbang series; one questionable outcrop of solid bitumen was observed, in loose débris, which appears to overlie the Vigo shale; and a heavy, black oil, or viscous bitumen, was found in sandstone near the base of the Vigo.

The bitumens in the Canguinsa are encountered in five types of deposits as follows: (*a*) Solid bitumens, in lenses or pockets which tend to follow bedding planes, but which also cross the bedding irregularly along fractures and cavities; (*b*) solid bitumens, in regular fissures, which penetrate the clay-tuff independently of bedding planes; (*c*) nonuniform mixtures of bitumen-impregnated, clay-tuff fragments and subordinate solid bitumen; (*d*) viscous, or semiliquid, bitumen-cementing breccias of flintlike limestone, small domes of which protrude from the surface of the clay-tuff formation; and (*e*) viscous or semisolid bitumen, filling the centers of hollow, cylindrical concretions, which occur in the clay tuff, with their longer axes nearly vertical and at right angles to bedding planes.

The bitumen in the Malumbang series has impregnated porous limestone and sandstone, forming what is known commercially as rock asphalt. It is this material impregnating the porous limestones of that region which the Leyte Asphalt and Mineral Company is developing. To me there appeared several million tons of this material available; Dalburg estimates about ten million tons. The best deposit known at present is on the Lucio claim.

MINDANAO

The Pidatan field was investigated by me late in February, 1921, in company with Pittsburgh (Pa.) oil men and geologists. About one week was spent on the ground in the vicinity of the petroleum seep. It was the consensus of the entire party that

the immediate vicinity of the seep did not show sufficient favorable indications to encourage drilling in that particular region, but it did seem justifiable to consider further geologic exploration in the surrounding territory in Cotabato Province.

The field investigated is situated about 60 kilometers due north of Fort Pikit, Cotabato Province, which in turn is situated some 70 kilometers up the Rio Grande de Cotabato and, therefore, is very nearly in the heart of the great southern island. To the north of the field lies the volcanic range containing the active volcano of Mount Ragang, which in turn lies just south of Lake Lanao. To the west runs the line of hills and mountains known as the Babuy Mountains. To the east there are some moderately high hills and mountains of limestone, of which Mount Kitubud is the outstanding feature. The principal stream through the field is the Malitabug, which flows almost due south. This is a swift and almost unfordable tributary of the Rio Grande.

Transportation to the seep is first by launch from Cotabato to Fort Pikit, thence by horse and cargadores up Malitabug River, thence across country to within about 1.5 kilometers of the oil seep. The rest of the way is made on foot. The trail as far as the forks, close to Banisilan, is a fairly good one; from here it ascends gradually to an elevation of between 750 and 900 meters, and is exceedingly rough in places. The country is practically uninhabited, and side trails are few. Tall grass (cogon and talahib) runs riot, and much of the country is fairly deforested. With the exception of Banisilan, where there are a Constabulary outpost and a Moro farm school under the able supervision of Mr. Manion, there is no settlement worthy of the name. The country is exceedingly wild and beautiful and capable of great development. There is a Government herd of cattle here, the only one in hundreds of square kilometers of country.

The geology of the region, briefly stated, is as follows: The principal formation as indicated on an early map published by the division of mines of the Bureau of Science consists of Tertiary sediments, limestones, sandstones, and shales. These are intruded on the edges of the field by igneous rocks, principally basalts and andesites. There is considerable agglomerate in the region. Owing to these intrusions, and also to more-widespread regional earth movements, the sediments have been folded and faulted, as in other parts of the Archipelago—some of them, especially the lower series, including the Vigo shales, very pro-

foundly. In the region adjacent to the seep the formations which might be counted upon to contain oil are so badly disturbed that no regular structures could be made out; and, as knowledge of the geologic structure is necessary in locating an oil field, a favorable consideration of this locality cannot be entertained. I do not mean to say that no oil exists there: it might even be there in fair quantity; but with other difficulties, already referred to and which must be considered, it does not promise to be an economic undertaking. This is a feature which many would-be oil producers do not adequately consider.

The seep under discussion is located in a small ravine, the headwaters of Kirusoy Creek, a tributary of the Malitabug, on the side of a partially wooded range of igneous rock and on the south side of an east and west dike extending from the main igneous mass. Apparently, there is a fault at this point, as the oil is seeping out along a considerably slickensided surface. On the hanging wall there is a much broken mass of material which may be either agglomerate, locally brecciated igneous rock, or merely talus. Little oil or gas is issuing at this point. The location and the composition of the oil (which has none of the light fractions and very little either of paraffine or of asphalt) indicate local and abnormal conditions. Compared with other seeps seen in other parts of the world by members of our party, this one was disappointing.

CEBU

Just prior to the outbreak of the insurrection of 1896 an English company had started drilling on the Smith Bell Estate near Toledo, Cebu; but with the coming of hostilities work was abandoned when the bore had reached about 400 meters. A small amount of oil had been tapped, and it can now be baled from the old well.

Although there are several strong seeps on the west coast of Cebu, the geologic conditions are not so favorable as are those on Bondoc Peninsula. At Alegria, on the southwestern coast, the seep is located near a fault, and the topography is such that drilling operations would be expensive. Farther north, at the old Smith Bell well near Toledo, the rocks are found in a monoclinal attitude in which there are minor folds. Detailed work in that region has revealed some unfavorable structural features. However, between these two localities, or farther to the north of Toledo, favorable structures might be located.

MINDORO

Two seeps are reported on Mindoro, one near Mangarin, and the other farther back in the foothills to the northeast of this place. I know nothing at first hand of either of these localities and, as far as I know, no published information is available.*

PANAY

On Panay Tertiary shales that yield natural gas are found on the eastern flanks of the main cordillera, generally monoclinal; that is, dipping in one direction, to the east. From work already done in that region it is known that there is at least one well-defined local anticline, known as the Maasin anticline, which might be a favorable location for a test well. However, some comparatively deep artesian wells in that region, which have reached a depth of 527 meters, have shown only small amounts of natural gas and salt water.

SULU GROUP

A petroleum seep is reported by observers of the Coast and Geodetic Survey, on Siasi Island, between Jolo and Tawitawi, in the Sulu group. I doubt the genuineness of this seep since there is a great amount of volcanic veneer on those islands. However, this does not preclude the possibility of finding Tertiary sediments beneath.

CHEMICAL AND PHYSICAL PROPERTIES OF PHILIPPINE PETROLEUM AND NATURAL BITUMENS

Philippine petroleum has a paraffine base and is usually reddish to violet in color. It is clear, and closely resembles oil from Burma and Sumatra. Table 36 gives a fairly complete analysis made by Richmond and other former chemists of the Bureau of Science. Table 36*a* shows the physical and chemical properties of petroleum from Pidatan, Mindanao. Table 37 gives an analysis of the petroleum residues from Leyte Island. The paraffine content of Philippine petroleum is very high; a bottle full of oil collected in 1908 from the Toledo well and put, imperfectly sealed, into one of my saddle bags, was found, on unpacking three days later, to contain no oil; but it was half full of solid paraffine.

* Geologists of the Richmond Petroleum Company and of the Dutch Shell Company have made examinations here, but the results have not been made public.

TABLE 36.—*Physical and chemical properties of Philippine petroleum.*

Sample.	Crude oil.		Distillation products.						Residue above 400° C.	Remarks.
	Color by transmitted light.	Specific gravity.	Gasoline, to 150° C.		Kerosene, 150° to 300° C.		Heavy oils, 300° to 400° C.			
			Volume.	Specific gravity.	Volume.	Specific gravity.	Volume.	Specific gravity.		
Tayabas, Bahay well I.[a]	Brown to wine red.	0 8325	39	0.770	44 5	0.850	16 5	----------	----------	Flash point, 0° C. (32° F.); sulphur absent; initial boiling point, 91o C., paraffine, 8.1 per cent; specific gravity at 15° C.
Well at Toledo, Cebu	Dark brown	0 885	6 2	0 762	42 32	0 832	38.3	0 901	+3 17	Residue above 375° C. specific gravity at 15° C
Oil seep at Alegria, Cebu	do	----------	17 5	----------	30 5	----------	35	----------	----------	Residue contained foreign sediment
Leyte	----------	0 926	----------	----------	----------	----------	----------	----------	----------	Flash point, 74° C. (166° F.).

[a] Depth, 40 meters. Sampled by division of mines twenty-four hours after well had been drained.

TABLE 36*a*.—*Physical and chemical properties of a sample of petroleum from Pidatan, Mindanao.*

Specific gravity at 15.6° C	0.9297
Distillation:	
Light oils (below 150° C.)	None.
Burning oils (150°–300° C.)	45 per cent by volume.
Heavy oils (300°–400° C.)	49.5 per cent by volume.
Residue	5.5 per cent.
Sediment	Large amount.
Water	Trace.
Base	Paraffine.
Main calories, or gross heating value	12,495
Available heating value	11,189
Sulphur	1.56 per cent.

TABLE 37.—*Physical properties of natural bitumens from outcrop A and B, Villaba, Leyte.*

Property.	
Specific gravity	1.05
Hardness	2.00
Color	Jet black.
Streak	Black.
Luster	Brilliant.
Structure	Columnar.
Fracture	Conchoidal.

Intumesces, softens, and flows imperfectly at 150° C.

ROCK, SAND, AND GRAVEL

Many people overlook such plebeian items as rock, sand, and gravel, because they are found nearly everywhere and it is not usual to think of value in connection with such common articles. However, the production of these items in 1920 amounted to one and a quarter million pesos. It is interesting to note that one of the contractors doing the largest business in this material in the city of Manila is a Tagalog woman. The largest producer of pig iron in the Philippines is also a Tagalog woman, from Angat.

SALT

Most domestic salt in the Philippines is produced by solar evaporation of sea water, and much of the production is a household industry. However, in some parts of the Islands, particularly in northern Luzon, there are salt springs from which a considerable quantity of salt is secured. The hot waters from these springs are also prized as curatives for skin troubles. The best-known salt springs in Luzon are at Mainit, near Bontoc, and at Asin, near Buguias, both in the Cordillera Central.

STONE

Virtually all of the stone quarried in the Philippines is used either for concrete construction or for macadam roads, and only a small amount is utilized as building and ornamental stone.

The principal building stone in the Philippines is a volcanic tuff known as Meycauayan stone and Guadalupe stone. Many of the large and older public buildings in Manila are made of this material. It is moderately tough, durable, and elastic and a good construction material for a country where earthquakes occur frequently.

The principal ornamental stone is Romblon marble, but this stone is not altogether free from small fissures and seams, features that are unfavorable.

Coral limestone has been quarried in the past in many islands, notably Cebu, for construction material. Many churches are made of this material. Magellan's monument on Mactan Island is constructed of this stone.

There is an abundance of granitic rocks, such as diorite, which might be used, but these have been quarried only to a limited extent. One still sees in the older parts of Manila slabs of granite which were imported from Hongkong. Stone quite as good, though probably not so accessible, can be found in many parts of the Philippines.

SULPHUR *

Practically all the sulphur mined in the Philippines at present comes from Silay, Occidental Negros. Deposits of fair size are known on Camiguin Island in the Babuyanes, north of Luzon, but mining operations there have now ceased. Around many of the old solfataras in the Philippines there are by no means inconsiderable deposits of sulphur which might be utilized, as was done in earlier days on Biliran Island and the north coast of Leyte. The recent notable researches in the application of sulphur in scientific agriculture, made at the Oregon Agricultural College in the United States, indicate that the farmers of the future, even those in the Philippines, will create a steady demand for this mineral. The growing importance of sulphur as a fertilizer, in addition to its other important uses, adds interest to the Philippine deposits. The best-known localities are Silay, Negros; Camiguin Island, north of Luzon; Biliran Island and Leyte; and Mount Apo.

* The notes on Sulphur are taken largely from papers by Goodman, Ferguson, Elicaño, and Smith.

SILAY, NEGROS

At present the only sulphur mining recorded is near Silay, Negros. Of these deposits Elicaño says:

There are three sulphur deposits, namely, the Malisbog, claimed by Mr. Gerardo Alunan; the one at Mount Azufre claimed by a company called Los Valientes, in which Senator Guanco, Mr. Ortega, Mr. Jalandoni, and others are interested; and the one on the other side of Mount Azufre, also claimed by Mr. Gerardo Alunan. The Malisbog is about 29 kilometers from Silay, while the other two are about 36 kilometers from the town. All of them lie in areas southeast of Silay.

There is a good automobile road of 13 kilometers to Guimbalaon barrio; from this to Agho there is a cart road of 3 kilometers; from Agho to the deposits there are only trails, which in some places are dangerous to follow owing to the steepness of the hills. The deposits are all solfataric in character. The sulphur is found around vents from which emanate gaseous and steam vapors, those near the craters or vents being pure. The deposit of the Los Valientes does not exceed 1 hectare in area, though the area claimed is 64 hectares. The total available ore in this deposit will probably not exceed 300 tons. The other claims are still smaller than that of Los Valientes.

CAMIGUIN (NORTH)

Of the deposits on Camiguin, in the Babuyanes group north of Luzon, Ferguson wrote the following in 1910:

The principal feature of the economic geology of Camiguin is its solfatara on the west flank of the mountain about 2 kilometers from the sea. This is between 600 and 800 meters in length and perhaps 100 meters wide, following a dry stream bed. The sulphur is very fine and while of course the depth of the deposit is unknown there seems to be a considerable amount of it. The stream vents are not very numerous and there is no troublesome flow of hot water. A solfatara which had been worked commercially in Iceland had a smaller surface area of sulphur, less favorable topography and no local fuel supply. A stream of scalding water had to be diverted before operations could be begun, work could only be carried on during a part of the year, and the sulphur, not as pure as the Camiguin sulphur, had to be carried by ponies a three-days' journey over rough mountain trails to the point of shipment and all supplies carried in the same way. It was this last item which caused the abandonment of the Icelandic sulphur. If test pits should show the Camiguin deposit large enough to warrant development, there is abundant wood-fuel at hand and the sulphur could be purified before shipment. It would only be necessary to pack the sulphur about two kilometers to the beach where it could be sent by native boat to Aparri and there transhipped (or purified there, as there is an undevoloped coal deposit not far up the Cagayan River) or else it could be carried in small boats to Porto San Pio V where steamers might call. The chief problem would be labor, as it is doubtful if the natives of northern Luzon or the Batanes could be induced to work on Camiguin Island. The isolated situation and the long stormy season are also drawbacks.

Analysis of an average sample of this sulphur for percentage of sulphur and the two impurities which can not be freed, arsenic and selenium, made by Reibling, gave the following results: Sulphur, 81.6 per cent; arsenic, trace only; selenium, none.

I am informed that on the east flank of the mountain there is another even larger solfatara, but I was not able to visit it.

The sulphur of Camiguin deserves investigation. Test pits should be sunk to bed rock to ascertain the depth of the deposit in the known solfataras and the region around the volcano should be thoroughly explored in the hope of discovering new deposits. Native information can not be depended upon as the natives have a superstitious dread of the mountain and it is only with great difficulty that they can be induced to go there.

Since Ferguson's visit to Camiguin several sporadic attempts at mining the sulphur there have been made, the chief person responsible for that activity being the well-known prospector and promoter Capt. F. D. Burdette. It has been estimated by persons connected with the project that there are 4,100 tons of commercial sulphur in sight.

BILIRAN AND LEYTE DEPOSIT *

The source of the heat and sulphur carried by the Mainit lies in the solfatara, which is only about one-half kilometer east of where we crossed the river and about 30 meters above it. The To-od Grande, as this solfatara is called, is a large barren space about 250 meters long by 150 meters wide. Its surface consists of white kaolin resulting from the corrosion by acid fumes of some volcanic rock, probably andesite. A portion of this superficial layer has encrusted upon it a greenish yellow mixture of sulphur and clay, deposited from the sulphuric gases which still emanate from numerous fissures and craterlike openings in the surface of this barren area.

These openings are of two kinds: dry vents from which gases escape into the atmosphere without the association of water, and wet holes which are like large earthen caldrons containing either boiling mud or water. Extending some distance around the orifice of the dry vents there is usually formed an incrustation of beautiful yellow crystals of sulphur. The bulk of the sulphur, however, lies in the impure clayey mixture distributed over the surface in irregular patches. An average sample of the crust to a depth of about 20 centimeters yielded on analysis 66.1 per cent of free sulphur.

The To-od Pequeño is a continuation of the same solfatara, situated to the south of and at a lower level than the To-od Grande. It exhibits the same phenomena as the upper solfatara, but is much smaller in area. In one portion of the To-od Pequeño is a large cave from the bottom of which issue steam, sulphur dioxide, chlorine, and other gases, corroding the sides and roof of the vault and giving to it a varicolored appearance, due to the secondary minerals formed.

About 1 kilometer southeast of the To-od and separated from it by a high ridge of andesite is another solfatara called the Pangujaan. It is

* From a manuscript report.

situated on the southern slope of a slide, about 40 meters high and about 90 meters wide, from the sides of which four or five larger and several more smaller vents give off steam and sulphurous gases in a continuous flow. As at the To-od, these vents are usually ringed with a sublimate of sulphur, close approach to which, however, is very difficult on account of the precipitousness of the slide as well as on account of the heat and obnoxious gases given off. Occasionally the channel leading to one of these vents may become closed, and the flow of gases deflected in another direction, in which event the rich sublimate which has formed in the neck and about the mouth of the vent becomes covered over with a subsequent layer of kaolin, forming a hidden deposit of almost pure sulphur.

About 5 kilometers southwest of Capiñajan is situated Mount Guirón upon the slopes of which are located the two most important solfataras on the Island of Biliran. The San Antonio, situated on the western slope, at an altitude of about 335 meters, comprises 1 pertenencia, and the Santa Rosalia, situated on the eastern slope, about 185 meters higher than the San Antonio, comprises 2 pertenencias. Both these concessions were granted to Prudencio Ruiz, about the year 1880. During his lifetime, Mr. Ruiz spent considerable money in the development of his two concessions, mainly in the construction of roads and pack trails between the solfataras and the towns of Naval and Caibiran, situated respectively on the west and east coast of the Island of Biliran. Another trail passed over Mount Guirón between the two solfataras, making the connecting link in a direct route between Naval and Caibiran. Although for the most part still well defined and easily passable, portions of the trail have become so overgrown that this route across the island has fallen into general disuse. Mr. Ruiz died in the early eighties, and the sulphur mines have been abandoned ever since.

The San Antonio solfatara, in its general aspect, is very similar to the To-od south of Burauen, but on a smaller scale, possessing an open expanse of only about 76 by 107 meters or about one-fifth that of the To-od. Its surface is pierced by numerous vents, some of them as large as 3 meters in diameter, presenting the same phenomena as are exhibited in the To-od. The highest temperature recorded in the examination of several wet holes was 99° C. which is the boiling point of water at this altitude. The hot gases emitted from the dry holes made it impossible to approach them close enough to observe their temperature with an ordinary thermometer.

The Santa Rosalia solfatara is situated at the head of the Mapulá River, which flows eastward and empties into the Caibiran River near the town of Caibiran. It differs from the San Antonio and the To-od solfataras in that it does not lie upon a barren and comparatively level flat, but covers both sides and bottom of a low steep ridge and gully. It differs also in that it is no longer active, though apparently but recently extinguished. The Mapulá which flows about 75 meters below the solfatara is so highly mineralized as to be unfit to drink, and its temperature in the neighborhood of the solfatara is about 35° C. With the exception of the Guizo, it is also the poorest of all the solfataras visited in Leyte, both in quantity and in quality of the sulphur ore. That this condition may be due to previous exploitation is likely.

To make a close estimate of the amount of sulphur available in any of the solfataras mentioned is impossible, on account of the irregularity of the deposit not only superficially but probably in depth as well. From such data as I obtained from a superficial examination alone, it is estimated that about 3,000 tons of sulphur are in sight at the To-od and Pangujaan solfataras south of Burauen, while at the San Antonio, on the Island of Biliran, the estimated amount is about 400 tons. The sulphur in sight at the Santa Rosalia is inappreciable in amount.

Of the sulphur in sight there must be deducted at least 25 per cent for losses in mining and treatment of the sulphur ore, which leaves about 2,250 tons obtainable at the Burauen solfataras and only about 300 tons at the San Antonio.

MOUNT APO

I visited Mount Apo in 1908 and above 1,400 meters elevation found half a dozen or more fair-sized gas vents about which had accumulated small mounds of nearly pure sulphur. Probably there are between 500 and 1,000 tons in sight on the mountain, and probably much more permeating the rocks. However, the deposits are not very accessible, as it is a difficult matter to climb Mount Apo, about two full days being required to travel from the coast to the solfataras.

MISCELLANEOUS LOCALITIES

Some very good samples of sulphur from Camiguin Island, Misamis Province, Mindanao, are in the collections of the Bureau of Science, but those who have investigated the deposits recently report only a limited supply. Some solfataras with a small supply of sulphur are known in the Pocdol Mountains, Sorsogon Province, Luzon, but these have not been investigated by Government geologists.

It is not surprising, in a country of such recent and widespread volcanism, to find numerous solfataras, and from some of them undoubtedly commercial supplies of sulphur will be obtained when the demand becomes great enough to encourage their exploitation.

MINERAL WATERS

There are many kinds of mineral water in the Philippines. In spite of the existence of many fine natural waters, the largest production from any one source is that from Los Baños, in Laguna Province, where an artificially charged water is bottled and sold under the name of Isuan.

Bottled waters valued at about 100,000 pesos are imported into the Philippines every year, all of which might be replaced by domestic waters of equal quality.

In the discussion of mineral waters, we must not overlook the hundreds of excellent wells that have been drilled in the last few years in all parts of the Archipelago. Water from deep sources has been a large factor in the greatly improved health conditions among Filipinos, and a very appreciable betterment in the physique of the people, as a result of good water together with good food, is to be noted. It is difficult to place a money value upon this water.

To appreciate the importance of good potable water the reader has but to peruse the health records of the Philippine Islands before and since the use of deep-well water. Previous to 1905 there was scarcely a well other than the shallow, dangerous, dry wells which were merely cisterns for contaminated surface water. At present there are close to two thousand wells, generally classed as artesian (though not all can be strictly so called) in the Archipelago, most of which yield water.

The formations in the Philippines most suitable for this kind of well are porous sands and tuffs in monoclinal or synclinal structures confined by impervious beds; that is, when the water-bearing strata dip in single incline, one way, or form a basin, the essential points being a higher source, porous strata, and impervious cover. The interbedded tuffs and sands of the Manila plain offer the best sources of artesian water in the Philippines. Next to these come the older Tertiary sandstones and shales which overlap the igneous cordilleras and dip away from them in a monocline to the valleys.

Much investigation was carried out in Spanish times by various Government chemists and geologists, chief among whom were Abella and Centeno, and the work has been continued, with more or less interruption, by Americans and Filipinos in the Bureau of Science. In 1918 George W. Heise and A. S. Behrman wrote a complete summary(314) of the work accomplished. I have selected the following excerpts from their publication as most pertinent for use here:

> The term "mineral water" is somewhat confusing. Practically all natural waters contain dissolved mineral matter and might be properly classified as mineral waters. However, in the more restricted meaning of the term, only those waters are included that have peculiar characteristics distinguishing them from ordinary spring or well water. According to Grünhut, a mineral water is identified by (a) a high content of soluble matter, (b) a high content of rare or unusual substances, or (c) a high temperature.

One of the best systems of classification is that of Haywood and Smith, which is generally used in technical work. A simpler, less complete classification, sufficient for the purpose of this paper, is as follows:

I. Thermal. Example, Los Baños springs, Laguna.
II. Carbonated (or bicarbonated).
 1. Alkaline, containing:
 a. Sodium bicarbonate.
 b. Potassium bicarbonate (rarely). Example, Dinalupihan Spring, Bataan.
 2. Magnesium, containing:
 a. Magnesium bicarbonate. Example, Hot Spring, Puerto Galera, Mindoro.
 3. Calcareous, containing:
 a. Calcium bicarbonate. Example, Bolocboloc Spring, Barili, Cebu.
III. Chalybeate (iron, ferruginous).
 1. Containing the sulphate or bicarbonate of iron. Example, Lanot Spring, Ambos Camarines.
IV. Muriated waters.
 1. Containing salts, mainly sodium or potassium chlorides. Example, Mainit Spring, Bontoc.
V. Aperient or sulphated waters.
 1. Containing sodium sulphate (Glauber's salt). Example, Klondike Spring, Benguet.
 2. Magnesium sulphate (Epsom salt). Example, Tancalao Spring, Tabaco, Albay.
VI. Bromide and iodide waters.
 1. Containing the bromides or iodides of sodium and potassium. Examples, Maaslom Spring, Cebu. (Few definitely known in the Philippines.)
VII. Sulphuretted or hepatic waters.
 1. Containing sodium or hydrogen sulphide. Example, Sibul Spring, Bulacan.
VIII. Arsenical.
 1. Containing arsenic. Example, Tiwi Spring, Albay.
IX. Lithia.
 1. Containing lithium salts. No good example known.

No systematic study of mineral waters has been yet undertaken on a large scale by the Bureau of Science, so that our records are still too incomplete to warrant a detailed discussion of the springs of the Philippines. The best published data on this subject are the monographs and bulletins of the Spanish Government, to which reference was made in the first footnote. *

Practically every province in the Philippines has many excellent springs, some of them with great reputations for medicinal virtues. In addition, the drilling of artesian wells has made available a large number of excellent mineral waters. Popular preference, however, is usually given to water from a spring.

A few of the more important Philippine mineral waters are briefly described below. The list contains only those that have been examined by members of the Bureau of Science staff and includes several that are not really mineral waters, but that have reputations for medicinal properties.

Albay.—The hot springs at Tiui have been described by Adams and Pratt, as follows:

Tiui Hot Spring.—The most noted hot springs of this region are near Tiui; they have been described by Jagor, von Drasche, and Abella.(7) Abella considered them as subordinate volcanic emanations of Malinao.

"Hot water accompanied by sulphurous gas issues at a place termed Jigabo, in the bed of a small stream, the Naga. This place has the nature of a fumarole. The stones in the river bed have been largely decomposed by the chemical action of the waters, and the ground and stones in places are coated with a sulphurous efflorescence. This spot is but a short distance to the west of Tiui."

The waters are thermal, sulphuretted, and arsenical.

Ambos Camarines.—The Lanot and other springs on the west coast of San Miguel Bay are ferruginous, carbonated.

Batangas.—There are a number of thermal and other mineral springs in Batangas, which, however, have not been much studied. A flowing artesian well at Batangas is worthy of mention (see radioactivity) as the most radioactive source yet found in the Philippines.

Bulacan.—Of the many mineral waters of Bulacan Province, only two have been sufficiently studied to merit description here.

The springs at Sibul are nonthermal, mildly sulphuretted sources of very great capacity. A splendid bathhouse has been erected here by the Insular Government. People come great distances for the waters, which have, perhaps, the greatest reputation for medicinal virtues of any waters in the Islands. The usual statements based on the chemical analysis regarding the therapeutic value of these springs are undoubtedly erroneous, as the waters are only moderately mineralized. However, the springs are among the most radioactive yet found in the Philippines.

The artesian well at Marilao has acquired a great reputation, and a bathhouse has been built. The waters are nonthermal and are not sufficiently mineralized to be classed as mineral waters. They are not radioactive. There is no apparent reason why they should be considered medicinal.

Cebu has many excellent thermal and mineral springs. Bolocboloc Spring, at Barili, is nonthermal, sulphuretted, bicarbonated, carbon-dioxated. Other sources are "Mainit," Naga, a thermal spring; a nonthermal sulphuretted spring at Dumanjug; a hot spring at Malabuyoc; and others, whose analyses are shown in the tabular data.

Iloilo.—Perhaps the best-known springs are those on Guimaras Island. They are chiefly nonthermal, calcic, carbonated.

Laguna.—Laguna Province is well supplied with springs, especially in the vicinity of Mounts Maquiling, Banajao, and San Cristobal.

There are many springs in the neighborhood of Los Baños and on the slopes of Mount Maquiling. A large sanatorium has been erected at the town of Los Baños, which attracts many visitors.

The Los Baños hot springs are only moderately mineralized. They are, however, the most highly radioactive thermal sources known in the Philippines.

Pansol Springs, between Calamba and Los Baños, have no abnormal chemical characteristics. It is popularly believed that they are alternately hot and cold. This erroneous impression is due to the fact that they are really a series of hot and cold springs, of very different chemical composition, which emerge into the same pool of water. These springs are located in a very beautiful grotto.

A large spring, called Bumbungan, is located near Pagsanjan, on the river bank near the famous Pagsanjan gorge. A stone bathhouse, dating back to Spanish times, has been erected. The water is of very ordinary mineral composition and is only very moderately radioactive.

There is a very picturesque spring at Pakil, which flows into a large pool or basin. Medicinal properties are attributed to this source, and religious pilgrimages are made to it. The water is only slightly mineralized and is moderately radioactive.

Among other well-known springs, the following may be mentioned: Sinabac, Majayjay, of ordinary mineral composition but highly radioactive, and a series of moderately radioactive springs of no abnormal chemical characteristics, such as San Diego and San Vicente, Nagcarlan; Baño and Bañadero, San Pablo; and San Mateo, Lilio.

Mountain Province.—As might be expected in a volcanic, mountainous region, Mountain Province is plentifully supplied with springs. Owing to the difficulty of travel and the backward state of the inhabitants, these springs are comparatively little visited. Only a few of the better known hot and heavily mineralized springs will be mentioned here.

Klondike springs are situated on Benguet Road, on the west bank of Bued River. They are very hot and only moderately mineralized and sulphated.

There is a series of hot, sulphuretted springs that have been used for medicinal purposes for many years about a kilometer below Balongabong, or Twin Peaks, on the west bank of Bued River. These springs have a temperature of 50° C.

At Itogon, only 15 to 17 kilometers from Baguio, is a series of hot, heavily mineralized springs, which were once much visited. In recent years a landslide covered some of them and changed the character of others, but they are still capable of development. As they are comparatively close to Baguio, they could be readily utilized.

The hot springs near Cervantes, notably at Comillas, also have a considerable reputation for medicinal virtues.

There is a remarkable series of springs at Kiangan used, in a great measure, for irrigation purposes. Though not characterized by any abnormal chemical ingredients, these springs are highly radioactive. One of these springs (Adukpung) is worthy of more than brief mention. It emerges from the wall of a rice paddy, only a few centimeters below the level of the water in the field, and has all the appearance of a seepage spring. It is asserted, however, that it flows throughout the year, even when the rice paddy is dry. The high radioactivity of this water and the data obtained from its chemical analysis as compared with that of

the rice paddy water indicate that it is a true spring. It would be interesting to examine the water-bearing strata at this place.

There are many saline springs, some of which are, or have been, used for salt making. Chief among these are the boiling hot Mainit Spring near Bontoc, whose waters, though used for salt manufacture, are also used for medicinal purposes; Balotoc, 10 kilometers east of Lubuagan, boiling hot and very highly mineralized; and Tukukan, Ahin, and Bungubungua, in Ifugao. Salt making at Amdangle, Ifugao, and at Asin, near Daklan, Benguet, has been discontinued, because landslides have ruined the springs.

Negros.—Springs of many different kinds are common on Negros, but no intensive study of them has been yet made. There is a small sulphuretted spring with reputed medicinal properties near Isabela, Occidental Negros. The springs at Mambucal on the sides of Mount Canlaon are very highly prized. Two springs in Oriental Negros are especially worthy of mention, namely, Masaplud, acid aluminic, sulphated, and a thermal saline spring at Palimpinon.

Nueva Vizcaya.—The mineral waters of Nueva Vizcaya have not been intensively studied. The saline spring at Salinas is used for salt-making. This spring issues from the top of a great white mound of calcium salts deposited from the water [Plate 20, fig. 2]. The water is only very slightly thermal.

Palawan.—There is a salt spring at Culion.

Sorsogon.—Many mineral waters are to be found in Sorsogon Province. A hot spring at Bulusan yields ferruginous, bicarbonated, muriated water; a thermal, carbonated spring is located at Irosin; a "gushing" artesian water at Sorsogon is calcic, carbonated.

METALLIC MINERALS

CHROMITE

Chromite has been found in the western cordillera of Panay near Valderrama, Antique Province, and in Ilocos Norte Province, but nowhere is it being mined. It is always associated with serpentine or serpentinized peridotites and pyroxenites (basic igneous rocks).

COPPER

There has been practically no production of copper during American occupation, although development work on the old Mankayan properties continues. Many examinations of this deposit have been made which reveal a fairly extensive, low-grade body of enargite. Practically the only economical way to handle this ore is to export it to some neighboring country where there are smelters. The copper market is too uncertain and the local obstacles, such as transportation, lack of timber, cost of smelter, labor, etc., are so great as hardly to be overcome.

Mention is made, in the earliest known records, of the existence of copper in the ancient province of Tuy, now called Mountain Province. When the Spaniards first landed in the Philippines they heard of copper smelting by the "Ugolotes," as the mountain people were then called. It seems very evident that the Chinese or Japanese taught them the art, probably in the days of Limahong, the noted Chinese pirate who invaded the Philippines in the sixteenth century and landed at Laoag, Ilocos Norte Province.

The copper deposits are located in and about the barrio of Mankayan, which is situated on a small plateau in the Cordillera Central of northern Luzon, about 16 kilometers south of Cervantes on Abra River. Mankayan is 264 kilometers due north of Manila, and 64 kilometers southeast of Candon and is reached from Manila by an excellent, graded horse trail from which there is a good trail, passable for bull carts, over the famous Tiela Pass. Mankayan is situated at an elevation of about 1,140 meters above sea level, and is distant from the coast town of Tagudin about 37 kilometers. The plateau is practically treeless, but there is more or less scattered pine timber on the adjacent hills and mountains.

The ore consists largely of arsenate of copper, with some secondary tetrahedrite in a quartz gangue. Secondary enrichment is clearly evident in the deposit at Mankayan. The main mass of the ore is of low grade (less than 2 per cent), but there is a considerable body that yields 5 per cent and more. Some very rich spots also exist. The following copper minerals have been found in this deposit: Enargite, luzonite (a special crystallization form of enargite), tetrahedrite, chalcopyrite, chalcocite, chalcanthite, azurite, and malachite.

The principal rock mass is diorite. This is capped by a so-called "trachyte" which is really a quartz porphyry. To the west is a great intrusive mass of quartz-diorite, known as the Bagan granite, while a little farther away and to the east is Mount Data, which consists largely of Tertiary andesitic agglomerates.

Eveland,(236) who in 1904 made the only geologic reconnaissance of this region, says of this deposit:

> The former attempts to explain the Mancayan deposit have been given and objections to each have been found, and as a mere tentative hypothesis may be suggested a genesis of these ores as yet not considered, that will be determined when further development work is done. It is

entirely within the grounds of probability, and not in conflict with any geological evidence so far at hand, to presume that, before the advent of the trachyte flow, ore deposits had been formed in the Mancayan diorite of a type similar to those at Suyoc—quartz veins carrying metallic sulphides and gold values. With the covering of the diorite and its veins by an igneous flow, chemical action was given an added impetus. The trachyte, easily decomposed and altered, was metamorphosed at its contact with the diorite to a hard, flinty, siliceous quartz porphyry, quartz replacing most of the other constituents of the rock. In its cooling and subsequent contraction fissures and crevices were formed, aided possibly by dynamic action, such as shattering shocks, which are a feature of the Islands. The heat of the overlying trachyte furnished a motive power for the process of vein deposition, and the heated waters, assumed to be rising, filled the cavities and cracks with silica and ore minerals obtained from lower or surrounding sources. Enargite is a prominent mineral among those formed by secondary action, and investigation shows that it has been formed later than the other minerals; so that the evidence points to a secondary enrichment of certain portions of the contact, notably at Mancayan, with copper minerals obtained from other sources. Deposition has taken place in all possible directions, leaving the irregular mass of veins of the Mancayan mine.

The influence of the granitic intrusion which cuts the older diorite seems not to have been considered by Eveland in the genesis of this ore deposit, but I am of the opinion that it has had a great deal to do with the mineralization of the region under discussion.

Santos, the eminent Spanish engineer, who was in charge of the Cantabro-Filipino Company in 1860, says of the local method of working and smelting these ores:

The mineral after being extracted from the mine is submitted first to a roasting, or, better yet, a crude melting; for this the natives open in the ground a hole one cuarta in diameter by two or three fingers deep, which they cover with some thin sticks forming a gridiron, above which they place a small, compact heap of mineral, held down by a board or piece of tree; and they cover all with thin pine wood, leaving a protected hollow above the board. They ignite this at once, leaving it alone until it has consumed the wood and completely heated the sulphur of the mineral, which takes two or three hours. The products are an impure mass of copper mixed with earthen substances and pieces of coal and scorias of quartz which offer the aspect of a breccia in which the cement has partly disappeared, converting it into a porous mass.

The copper matte then suffers a melting process for black copper, which they execute in the following manner: They make a hole six or eight fingers in diameter which they surround with stones forming a species of hearth or crucible, leaving an open space for the placing of a pipe connecting with a cylinder bellows. This consists of two cylinders made from a hollowed trunk of pine in which run pistons formed by blocks of wood dressed on their circumferences with dry herbs and chicken feathers,

which are held down only by the bellows, so they work in the manner of springs against the interior surface of the cylinders. In the lower part there is a hole and in that they place a cane, closing the valve at the beginning of the stroke.

Having formed the oven in this manner they charge it with pine fuel, mixed copper and matte, and put the bellows in motion, taking care to add the fuel in proportion to its consumption, and to agitate little by little with a cane so the copper may fall to the bottom and be cleaned from the foreign substances with which it may be mixed. When they know that the copper has all united into one mass, which should take place after ten or fifteen minutes, they stop the bellows and take out the coal and scorias which overfloat the metallic bath, leaving it uncovered untill it has hardened a little and acquired sufficient consistency so that it may be handled. The product is a cake of black copper of rough and broken surface full of earth and pieces of fuel.

This cake they place at once on a bonfire, where they leave it two or three hours, making it suffer a kind of roasting process which purifies it somewhat, and they afterwards melt it in the same furnace, placing it in a species of crucible or mold of refractory clay. At the end of this they put the crucible in the hole and over it they place the stone cover and surround it with fuel. They then force a blast, and after the copper is melted they uncover the bath, taking out all the impurities. They remove the crucible from the furnace, and later, when the mass has commenced to consolidate, they compress it with a stick. Finally they take the cake from the crucible, bury it in ashes until it has cooled, and smooth its surface a little by striking it with a stone.

The copper obtained in this manner they sell partly in cakes to the Christian people in the lowlands, and partly dedicate to the manufacture of pots and boilers which the Igorots forge with stones; also making of the same metal bars, tongs, and small pipes for smoking.

The Cantabro-Filipino Company was organized about 1860 with the Spanish engineer Santos in charge of the works. This company undertook to carry on more-modern operations and partially succeeded. Between 1860 and 1875 they extracted 2,500,000 pounds of copper. In the latter year Santos died at the mines, and all operations ceased soon after. Since then only desultory smelting has been carried on by Chinese and Igorots, who made considerable profits out of the rich dumps about the old Santa Barbara mine (fig. 20), the scene of the principal activities of the company.

At present (June, 1921) the P. C. Whitaker interests, with Victor Lednicky as mining engineer, are continuing the development of this property by driving two tunnels 32.7 meters and 65.4 meters, respectively, below (in elevation) the old Spanish drainage tunnel. Tunnel No. 1 is now 170 meters long, and No. 2 is 225 meters long, with a 40-meter drift. The vein in the lower tunnel is about 17 meters wide, strike north 45°

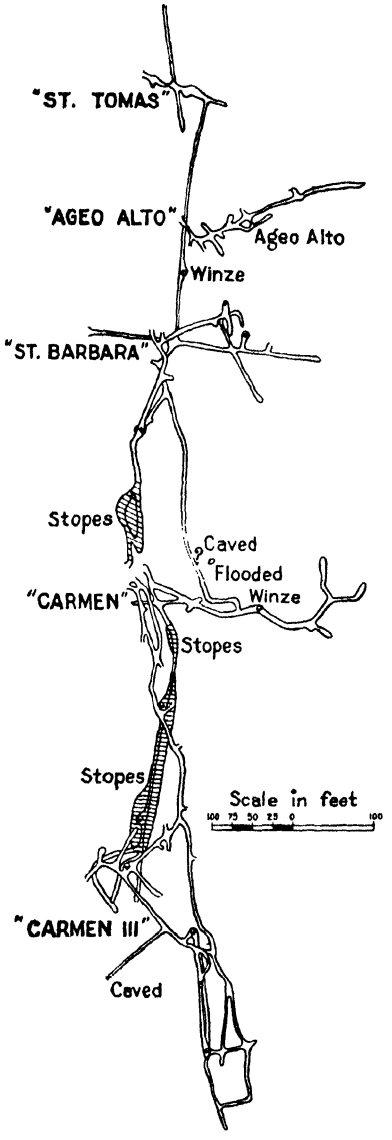


FIG. 20. Plan of the underground workings of the Santa Barbara copper mine, in Mankayan, Lepanto. Survey by Goodman and Ickis.

west, dip 65° northeast, and is said to yield about 2 per cent copper.

The deposits have been examined by several good engineers, who agree that there is an important body of ore in sight, averaging close to 2 per cent, with some very rich spots. The chief difficulties are transportation; lack of coke, which would have to be brought in or the ore shipped out; distance to a flux; and scarcity of timber and labor.

The only economical solution of this problem seems to be to concentrate the ore and ship it to Japan for smelting.

OTHER COPPER DEPOSITS

Copper in noticeable amounts has been found in at least two other localities in the Archipelago, but in neither has production attained any importance.

At Milagros, on the southwest coast of Masbate, native copper in andesite was worked some years ago, but no production has ever been recorded.

In the Loboo Mountains of Batangas Province I examined some gold- and copper-bearing quartz veins but, as a result of my unfavorable report, work on them ceased in 1905.

Near Sual, Pangasinan, some chalcopyrite deposits have been worked from time to time, but they have never attained any importance.

Some copper-bearing siliceous veins in andesite were prospected in 1913 and 1914, on the headwaters of Pula River, a

branch of the Aglao, in the Zambales Mountains of Luzon, but nothing of any moment has resulted from the prospects.

The uncertainty of the copper market, the difficulty of treating the ore, and proximity to the Japanese producers will always make copper mining in the Philippines a doubtful venture that should be undertaken by experienced persons only.

GOLD

Production of Philippine gold is higher than that of all other mineral products, and the industry remains almost entirely in the hands of Americans with some assistance from Australians and New Zealanders, who are first cousins to Americans in the mining business. In other countries the gold-mining business has fallen off greatly, but the Philippines has maintained a steady, though not large, output. The amount of gold produced during 1920 was only a few ounces less than during the banner year, 1916, when gold was actually worth more than it is now.

The Aroroy district leads the others in gold production owing to the continuous operation of its two mines, the Colorado and the Syndicate. Benguet, with a single large producer, alone almost equaling the combined production of the two in the Aroroy district, is second. Paracale, once in the limelight as a result of its rather remarkable, though small, dredging field, is to-day a mere reminiscence of its former self; only one dredge and a small ten-stamp mill are now operating.

The Benguet Consolidated, in Antamok Valley, has during the past few years, when many gold mines in other parts of the world have had to close down owing to the low purchasing power of gold, steadily paid dividends of from 25 to 35 per cent. At the present writing, the values on the lowest level of the mine are very encouraging, indicating possibly secondary enrichment in the vein. This mine is fast coming to be recognized as one of the notable small gold mines of the world.

The gold produced from Philippine mines during 1920 amounted to approximately 2,500,000 pesos; of this the Consolidated yielded 1,068,892.30 pesos.

In this chapter I have drawn freely upon an early paper by Eddingfield.(220) As I have since revisited most of the fields discussed in that paper I have accumulated new and fuller data in some cases which call for somewhat different interpretations. Nevertheless, it should be understood by the reader that Edding-

field does not incur any responsibility for modifications of his opinions which may appear in this chapter.

It is certain that gold has been extracted from the lodes and alluvials of the Philippines for centuries, long before the coming of the Spaniards. This is a matter of history and is covered in a later chapter.

Gold deposits have been found in nearly every island of the Philippine group; there is hardly a stream from which one cannot pan colors, or scarcely an area of igneous or metamorphic rocks wherein either large or small veins of gold-bearing quartz or calcite cannot be found.

In general we find the gold either in lodes (veins or ledges) or in alluvial accumulations known as placers. The latter class of deposits is further subdivided into high-level, or bench, placers and low-level deposits, in the river bottoms. Lodes are deposits in situ; the placers have been transported from lodes that exist elsewhere.

In the Philippines, as in other parts of the world generally, gold deposits, like most metalliferous deposits, are found in or near regions of igneous rocks; there are exceptions, where some lodes are near the contact of igneous rocks with sediments, or where the placers are found far down the streams in the flatter areas underlain by sediments.

As igneous rocks are the most resistant of the three classes and stand up as elevated masses, we naturally find the metalliferous lodes in or near the cordilleras. A few are found near old volcanic stocks or plugs, but scarcely any near recently active volcanoes. The gold deposits of the Philippines, like those of western America, are found associated with either andesites or diorites, principally; but, in one district, Paracale, they are in veins close to the contact of granite-gneiss and diorite-schist. By far the greatest number of veins is found in the andesite. Since there is, in some of the districts, both a later and an earlier andesite, and the paying veins are located in the earlier, it is important to be able to distinguish between them.

The vein matter fills fissures which are in many cases clearly tectonic. Faulting, with strong slickensides and considerable displacement of the veins, is pronounced in many districts. On this point I am not in agreement with Eddingfield, who expressed just the contrary opinion; later development in some of the districts, which he had not seen, has necessitated changing Eddingfield's statement.

The parallel arrangement of many of the fissures in all the fields, though less pronounced in Benguet, is noteworthy. The best lodes so far found and worked are in northwest and southeast fissures. It should be pointed out that these fissures are coincident in direction with one of the principal axes of the Archipelago.

In only one district (Baguio) has mining reached any considerable depth. In the Benguet Consolidated mine on the C level, at a depth of about 80 meters, the veins are keeping their width and values, and are even becoming richer.

According to Eddingfield,(220) the most characteristic feature in regard to the ore deposits of the Philippines is the abundance of quartz-calcite-manganese veins. This is true also of many of the Tertiary gold deposits of the western United States. A characteristic section of this type of vein in the zone of oxidation consists of (*a*) a band of solid compact calcite, varying in width from 0.5 to 6 meters, often lying next to the foot wall; (*b*) bands of black, soft manganese, usually mixed with quartz fragments or honeycomb quartz, and often containing pockets of white quartz crystals which in some mines indicate high values; these bands are found in some cases next to the calcite, in some cases next to the foot wall, and almost always next to the hanging wall; they vary in width from 0.2 to 4 meters; (*c*) a band of massive quartz, carrying sulphides and varying in width from 0.1 to 4 meters, usually separated from the calcite by a manganese band.

In some fields oxidation of the ores has gone on to a considerable degree due to the shattered condition of the veins and the inclosing rocks. In these much of the calcite has been dissolved out, leaving a honeycombed quartz. Concurrently, there has been mechanical enrichment of the veins for a short distance with a decrease of values with depth.

In many veins, in the Baguio district especially, there appears to be little or no oxidation and no secondary enrichment, either chemical or mechanical. Eddingfield devoted particular study to the subject of secondary enrichment in veins bearing manganese. Of the quartz-manganese deposits studied he says: "In all of the samples, the richest ore is at or near the surface and the values found so far appear to decrease with depth."

In calcite veins, Eddingfield was of the opinion that there was some enrichment, but of a mechanical rather than a chemical nature. Only recently have indications of enrichment in the

Benguet Consolidated mine been noted. The ore appears to be distinctly primary. This mine is now in its lowest workings, D-level, about 100 meters below water level.

Table 38 gives Eddingfield's excellent summary of the types of deposits in the several districts. To this I have added one or two important ones which he did not include.

According to the best authorities gold is deposited from solutions which are generally at high temperatures and are intimately related to deep-seated rock magmas. These solutions are in the first instance ascending, but descending solutions also play a part in deposition. With the gold content they reach fissures where they deposit siliceous and calciferous substances known as quartz and calcite, constituting the veins, or lodes. The fissures cut andesites, diorites, and granites, and even sedimentaries. In the Aroroy district they are in andesite, while in Benguet some are in andesite, others in diorite, and still others along contacts between sediments and the igneous rocks.

Philippine lode deposits appear to be of rather late origin, probably all dating from the Miocene Revolution. In Benguet it seems that the mineralization has continued into the Recent. Traces of gold can be detected in the travertine being deposited in the Itogon Hot Springs at the present time.

Values, of course, vary. Some very rich pockets running as high as several thousand pesos to the ton have been opened, but as a rule the ores are low grade. The Benguet Consolidated mine, the richest property in the Philippines, has an ore body that averages between 40 and 50 pesos (20 and 25 dollars) per ton. The Masbate ores run considerably less.

THE PARACALE DISTRICT (LODE AND PLACER)

History.—The Paracale-Mambulao gold field has for centuries been known to the Filipinos as rich in gold.

The first mention of this district of which we have an authentic record was in 1571. The Chinese and Filipinos worked the rich streaks and alluvial ground for many years in a crude way, until Spaniards from Mexico taught them to use the arrastre; a few years before American occupation nearly a score of these crude appliances were in use in the hills of this district. Small but fairly effective dipper dredges made of bamboo (Plate 24), which could handle only a few cubic meters a day, had been set in operation.

TABLE 38.—*Gold-bearing veins.*

SUYOC, BENGUET.

Mine.	Type of vein.	Width.	Strike.	Dip.	Vein filling.	Minerals.	Secondary enrichment.	Milling character.
		Meters.						
Elizabeth	Fissure	1	Northeast and southwest.		Quartz, calcite	Gold, copper, lead, zinc, iron, manganese.		
Quien Sabe	do	1 2	North and east.		Quartz	Gold, pyrites, copper.		
Palidan	do	1-5			do	Gold, pyrites		
BAGUIO, BENGUET.								
Headwaters	Fissure in andesite.	2-8	North 65° east	50° northwest.	Quartz, calcite, manganese.	Gold, galena, pyrites, manganese.	In manganese streaks.	Concentration in part, principally fine grinding and cyanidation.
Consolidated	do	10-30	South 70° east	65° southwest.	Crushed quartz	Gold, pyrites, manganese.	On foot and hanging walls and along manganese streaks.	Fine grinding and cyanidation.
Bua	Fissure in andesite (2 veins).	1.5 each	North 70° east	65° southwest.	Calcite, manganese.	do	In streaks of manganese.	Do.
Fianza	Fissure in andesite.	2-10	South 70° east	40° southwest.	Quartz	Gold pyrites	Enriched portion has been eroded.	Concentration, fine grinding, and cyanidation.
Madison	Fissure in andesite and partly contact with diorite.	5-10	South 55° east	85° southwest.	Quartz, calcite, manganese.	Gold, pyrites, manganese.	Very marked in manganese streaks.	Fine grinding and cyanidation.
Camote-Clayton	do	5-10	South 55° east	85° southwest.	do	do	do	Do.

TABLE 38.—*Gold-bearing veins*—Continued.

BAGUIO, BENGUET—Continued.

Mine.	Type of vein.	Width.	Strike.	Dip.	Vein filling.	Minerals.	Secondary enrichment.	Milling character.
		Meters.						
Magma	Fissure	50+	North and south.	East	Quartz	Gold, pyrites, sphalerites, etc.		Flotation (?).
Eileen	Fissure in andesite.	3	South 55° east	70° southwest	Quartz, calcite, manganese.	Gold, pyrites, manganese.	In streaks of manganese.	Cyanidation.
Lincoln Fraction	Fissure in diorite	5	do	45° southwest	Calcite	Gold, pyrites		
Kelly No. 3	Fissure in andesite.	3-5	East and west	70° south	Quartz	Gold, gold telluride, pyrites.	Along the walls	Concentration, followed by cyanidation.
Kelly South Slope	do	4-7	South 80° east	65° north	do	Gold, pyrites	General near surface.	
Muyot	do	3-6	do	do	do	Gold, pyrites, copper.	Occasional rich streaks; values are leached.	Concentration and cyanidation.
Tejon Dike	do	2-4	do		do	Gold, pyrites		
Emerald Creek	do	2-8	South 45° west	60° northwest	do	Gold	In seams and pockets, vein much oxidized.	
Major Engineer	Contact shale and andesite.	2-3	North 80° east	80° north	do	Gold, pyrites		
Major	Contact sand, stone, and andesite.	3-6	North 60° east	60° northwest	do	do		
Major Electrician	Fissure in andesite.	3-5	North 25° east	57° northwest	do	Gold		
Copper King	do	4-6	Approximately east and west.		do	Gold, pyrites, copper.		

AROROY, MASBATE.

Colorado	Fissure in andesite.	5	North 45° west.	70° northeast.	Quartz, manganese, calcite.	Gold, manganese.	Very marked in manganese streaks and by leaching out of calcite.	Cyanidation.
Eastern Nancy No. 1.	do	3-10	do	70° southwest.	do	Gold, pyrites, manganese.	Very marked in upper workings and along manganese streaks.	Do.
Keystone	do	3-5	North 40° west.		do	do		
Tengo	do	3-5			Brecciated quartz	Gold, pyrites	In upper workings.	

PARACALE, CAMARINES NORTE.

San Mauricio	Fissure in schist and gneiss.	1-3	North 10° east	70° southeast.	Quartz	Gold, silver, copper, pyrites, galena.	Along foot wall	Concentration and smelting or roasting and cyanidation.
Tumbaga	Contact andesite and sedimentaries.	Stringers	Northeast and southwest.		Calcite, quartz	Gold, lead, zinc, pyrites.		Free milling or concentration.
Longos Point	Fissure in gneiss	10	do		Quartz	Gold, pyrites		
Navotas	do	Stringers	do		do	Gold, lead, zinc		
Nalasvetan	Enriched zone in andesite.	5-10 (pocket)	North 30° west.		Silicified material	Gold, manganese, pyrites.	Surface	Free milling near the surface.

A large British corporation known as the Philippine Mineral Syndicate had acquired, just before the insurrection of 1896, extensive concessions from the Spanish Crown. Operations of a modern character were first undertaken on the Tumbaga property. However, these early attempts came to naught, owing to the disturbed political conditions.

Soon after order had been established in the Islands, discharged American soldiers and others were attracted to this region, and active development began. Finally, with the aid of New Zealand and Australian capital and miners, the district reached its peak of production and prosperity in 1914, when there were nine dredges at work. Since that time there has been a gradual decline, until to-day only one dredge is digging. There has never been any very successful quartz mining in the district.

The district comprises, roughly, 400 square kilometers of country of moderate relief. The topography is marked by a number of hills, which extend outward as spurs from the cordillera and have approximately a north and south trend. Between the hills are broad valleys, to a great extent filled with nipa and mangrove swamps. The whole country is densely wooded. The most-elevated point in the district is Mount Bonotan, some 500 meters in height.

Metamorphic rocks are a prominent feature of this area. The formations are pyroxenite, schist, granite-gneiss, shale, sandstone, and andesite, from north to south in the order named. The strike of the sedimentaries is, roughly, north and south, and they now stand nearly on end.

Prior to the Miocene disturbance, which flexed these formations into a more or less vertical position, the section of the strata was probably as follows: At the base a pyroxenite and diorite complex; above this sandstone, shales, and possibly limestone, with andesite overlying. With the Miocene uplift there probably occurred an intrusion of granite; exposures of the granite cutting across the basic rock can be seen. Along the contact of the two, gneiss and schist were developed. Later, and probably before the outflow of andesite, there began a period of vein filling and ore deposition. Naturally, the principal deposition took place along the weak zone of the contact and in the fractures adjacent to it. The principal lodes to-day are found normal to this granite-diorite contact. There are also many parallel veins running through this granite batholith.

The placer deposits are found along the rivers that cut across these veins and are naturally richer near them.

Mambulao.—In 1908 the ancient workings and those of the Philippine Mineral Syndicate (which were interrupted by the insurrection of 1896) were the only ones in the district, together with a few recent shafts and tunnels driven as assessment work. Shortly after, two companies developed and for a time worked two properties, the Tumbaga and the San Mauricio, which had been discovered and partially developed during Spanish times.

Tumbaga.—The Tumbaga property has only recently exhibited activity, though a few years ago it figured prominently in the local newspapers. It is one of those tantalizing deposits with exceptional streaks of high-grade ore, but apparently without body enough to put it in the producing class.

This property is situated 2.5 kilometers south of the town of Mambulao. The ore body is in a brecciated zone between a sort of arkose (more or less tuffaceous) and andesite. The trend of the ore body is northeast and southwest. In this there is considerable slate, through which innumerable calcite stringers ramify, some of which have been found to carry free gold. It is more than probable that the values will be found to be confined to these veinlets that cut the slate, and not in the body of slate itself as some have supposed. The absolute determination of this point will, of course, considerably affect our ideas as to the size and value of the deposit. The slate body is more or less lenticular and faulted and is about 10 meters wide.

Mr. A. C. Cavender worked this property for a time (from 1910 to 1912) with a small and rather inexpensive plant consisting of the following: Blake crusher, 5-foot Huntington mill, two Johnson concentrators, and the usual accessories. In November, 1909, on a trial run of twenty-two hours, 11 tons of ore produced 93.6 ounces, which represented merely the free-milling part of the ore. The hopes of the early operators of this property have not materialized, and to-day (1922) the plant is idle.

San Mauricio.—This property is located 1 kilometer from Mambulao, on the hill northeast of the town. The ore body is in part a quartz filling, normal to the contact between the granite and the basal rock, which here is more nearly a diorite than a pyroxenite.

In 1909 several hundred meters of drifts and crosscuts were opened. A drainage tunnel 500 meters long, from near sea level, was completed and connected with the main shaft.

Besides this development work, a 20-stamp Traylor mill, consisting of the following parts, was erected; 20 Traylor stamps, Blake crushers, Challenge feeders, 8 Traylor concentrators, and a Richard's classifier. The stamps are 1,050 pounds each, and it is proposed to have them dropped at the rate of ninety-four times a minute through a 5-inch drop. This mill, for completeness, general plan, and the way it has been set up, was a model at the time; it was, however, not altogether suited to the class of ore to be treated. The ore is basic, having copper, lead, zinc, and gold in gangue. In October of 1909 (?) a severe typhoon raged on this coast and did more or less damage to all the properties. At the San Mauricio mine the head frame was blown down, but no other serious damage was done. The property closed down in 1910.

Other lode properties on which development work has been carried on are the following: Dinaanan, north of San Mauricio; the Le Duc property, southwest of Mambulao; and the group of claims known as the Iron King, Gordon, Isla, Guinto, Abe Lincoln, and Navotas, all a short distance east of Tumbaga. All appear to be promising prospects, but nothing is being done on them.

Maliit—Some 6 kilometers south of Mambulao on Maliit Creek is located the only stamp mill operating to-day in the Paracale-Mambulao district. Messrs. Moisson and Mueller are operating a 10-stamp mill on a 3-meter quartz lode which averages about 16 to 18 pesos per ton. The country rock consists of slate and granite, and the ore body is near the contact. In all there are about 600 meters of workings.

THE PARACALE DISTRICT (PLACER)

Operations in this district (June, 1922) are confined entirely to placers, and only one dredge is working. This field reached its zenith in 1915, when there were nine dredges in Paracale River and adjacent streams, busy digging in the gold-bearing gravels and sands. These nine dredges included all the best-known models of dredges employing American, Australian, and New Zealand practices, making this perhaps the best place in the world to study the methods of gold dredging; nowhere else, to my knowledge, could comparative studies be made in such a limited area. These various types of dredges and the methods of operation have been fully described, both by technical representatives of the Government and by some of the company engineers, notably Mr. Kane.(348)

Paracale and Malaguit Rivers are comparatively short and nearly at sea level throughout their length. The Paracale is a good example of a drowned river. These two rivers lie in broad valleys, covered with mangrove and nipa palm, through which the dredges work their way. The mangrove is used for firewood and the nipa is either thrown aside or employed by the Filipinos for house building.

A test hole in a neighboring river, similar in many respects, which will serve to give a general idea of the ground to be dredged, showed the following:

TABLE 39.—*Strata in a river near Paracale.*

	Meters.
Soil, nipa, etc.	0–1.5
Sand and gravel, with some values in gold	1.5–7.6
Heavy black loam, with considerable decayed vegetable matter	7.6–11.5
Gravel "pay-streak"	11.5–12.2
Bedrock, soft, white, decomposed granite gneiss.	

Some of the ground, of course, is much deeper than is indicated by this boring and may even be as deep as 20 meters.

The ground in the vicinity of Paracale was unusually rich, yielding as high as 2 pesos per yard over considerable areas, while in several spots values as high as 14 pesos per cubic yard have been reported. The fresh, crystallized gold, showing little or no rounding, would indicate that it had not been transported very far.

This gold has so evidently come from lodes in the immediate vicinity of the placers that one is justified in looking for some paying quartz veins in the district. While some promising prospects have been discovered, there is no lode mining to-day in the Paracale portion of the district.

This district would show much greater progress to-day had some of the early promoters used better judgment. On account of some of their ill-advised ventures it is very difficult now to enlist adequate capital. Another drawback to the development of this district is the comparatively limited dredgeable ground.

THE ARoroy DISTRICT, MASBATE

The mining operations of the Aroroy district (Plate 35) have been discussed in various issues of the Mineral Resources of the Philippine Islands. A paper on the geology of that district, by Ferguson, with a geologic reconnaissance map, was

published in 1911.(274) The district has lately taken first rank among the gold fields of the Archipelago. A résumé of the history and geology of the Aroroy district follows.

History.—There are remains of mine workings in various parts of the Aroroy district which appear to be very old. Whether they represent the activities of Chinese before the Spanish conquest or are of a later period cannot be definitely ascertained; but it is claimed, in support of the theory of ancient workings, that pieces of Chinese pottery older than the Ming Dynasty have been found near the old tunnels and open cuts.

A story is told of the operations of a Spaniard and an Englishman who worked in the district long before American occupation. They had a shaft on the southwest side of Boston Hill and had struck rich, free-milling ore when the Spaniard murdered the Englishman. Some confirmation of the story is the fact that some of the best free-milling ore in the district is now being taken from veins near this site.

One of the first Americans to attract attention to the district was Mr. August Heise, at that time in the United States Army and stationed at Aroroy at the beginning of this century.

In 1904 and 1905 attempts were made to boom the placer prospects on Guinobatan and Lanang Rivers; but, though two dredges were installed there, no tangible results were achieved other than the sale of stock. One of the dredges was destroyed in a typhoon, and the other was later dismantled and transferred to the Paracale district.

In 1907 a small stamp mill was erected on Guinobatan River, a short distance above the present Syndicate Mining Company's mill site. This mill belonged to the now defunct Eastern Mining Company. It was never successful, and the holdings of that company were later taken over by the Syndicate Mining Company, which has been operating since 1914.

In 1911 a 20-stamp mill of modern design was erected on the claims originally located by Mr. Herbert on the north bank of Guinobatan River, about 2 kilometers below the old Eastern Mining Company mill. This mill has been running steadily ever since, and is one of the most consistent gold producers in the Archipelago. It is known as the Colorado property.

In 1913 a mill was erected on the Keystone property near Aroroy, but this concern has never been very successful and the mill was abandoned for a long time. To-day (1921) the Colorado and Syndicate are the only producers in the district.

Geology.—The principal rocks in the district, in the order of their abundance, are andesite, pyroclastics, quartz diorite, old slates, small amounts of limestone, and alluvium.

On the west side of Port Barrera is a large area of sediments of late Tertiary age. These dip gently to the southwest and, presumably, at one time overlapped the igneous core to the east, possibly extending over the whole area in the form of a broad arch. There are remnants of an older limestone as well on the top of the igneous in one or two localities. A reference to Ferguson's map shows that one of these remnants is found on Aroroy Mountain; it furnished lime for the cyanide plants near by.

To the east of Ambulong Peak (which is near the barrio of Aroroy), there is a fair-sized area of quartz-diorite; it is believed that considerable mineralization will be found in the neighborhood of that formation, as in the case of the Benguet district, where the best values so far have been found.

It has been noted by many who have visited this district that there is a strong system of veins striking northwest and southeast, the principal one being known locally as the Bronco lode. This system of veins is considerably interrupted, faulted, and offset laterally. The faulting would make it appear that there is a greater number of veins than really exist.

DESCRIPTION OF THE MORE-IMPORTANT PROPERTIES OF THE AROROY DISTRICT *

The Hayes property.—This property is situated in the extreme southern part of the district. Mr. Hayes, one of the first prospectors in the district, ran some crosscuts in an attempt to intersect the southeastward extension of the main lode of the district, which is locally known as the Bronco lode. No activity on this property is reported in 1921.

The Schwab property.—The next property north of the Hayes claims and on the south side of Boston Hill is being worked intermittently by Mr. Paul Schwab, one of the veteran American prospectors of the Archipelago. Mr. Schwab's mill, a small 1-stamp affair, is not now working. It is claimed that the best free-milling ore in the district is found here.

* In the case of the larger properties, I have purposely used information supplied by the officials of the companies. I have personally checked their statements in the field.

The Mount Cogran, Tuyo, and Gold Bug properties have all figured more or less in the history of the district, but none is producing at this date.

The Balete and Napuangan, now consolidated under the name of the Argus Mining Company, are two promising groups of claims in the extreme southern end of the district, located on some very fair veins in andesite. A small mill on the Balete property operated for a time, but only development work can be recorded now.

The Keystone Mining Company.—This is the northernmost property of the district, located on the north side of Aroroy Mountain. At the present time only development work is being carried on, but a very substantial mill, using Chilean mills instead of stamps, was operated for three years. At present very little of the old plant remains.

The Syndicate Mining Company.—This is the largest producer at present in the district and is the lineal descendant of the old Eastern mine of the early days of the American régime. To the engineer, Mr. T. Uewaki, in charge of surveying and drafting, and the mill superintendent, Mr. Enberg, I am indebted for a map (Plate 35) and the following very complete description of this property and of operations there:

BRIEF NOTES ON THE SYNDICATE MINE

The Syndicate Mining Co. is working chiefly three claims on the central part of Karabao Hill reserving the other thirty-one valuable claims.

The rocks covering the Syndicate area are almost entirely igneous, consisting chiefly of andesites, diorites, and pyroclastics in which numerous gold-bearing veins are found filling fissures. These veins are affected by many faults having nearly east and west or northwesterly courses.

The country rock in the oxidized zone is much altered near the veins; producing a brown, claylike rock generally showing traces of its original porphyritic structure.

The highest point on the outcrop of champion vein is 650 feet above the Guinobatan River level, which is generally considered as the permanent water level in this district.

The veins are developed in six levels, and the total length of tunnels exceeds 30,000 feet.

Among twenty-one different veins known, the principal ones that are in mining operation at present are the seven listed below.

1, 2, 3. The Star veins are composed of a very hard, dark blue quartz carrying irregular amounts of manganese and pyrite, the dark color being due to finely divided particles of manganese oxide.

4. The Bin Crosscut vein is of medium hard quartz, containing limonitic mud and manganese oxide.

Name of vein.	Type.	Width.	Known length.	Strike.	Dip to southwest.	Vein filling.	Minerals.
		Feet.	*Feet.*		°		
1. Star No. 1	Fissure	5	2,400	North 27° west.	85	Quartz, manganese, calcite.	Gold, silver, pyrite, manganese.
2. Star No. 2	do	4	350	North 30° west.	60	do	Do.
3. Star No. 3	do	6	420	North 40° west.	65	do	Do.
4 Bin Crosscut	do	10	1,700	North and south.	70	do	Do.
5. Nancy No. 1	do	3–20	1,250	North 30° west.	70	do	Do.
6 Nancy No. 2	do	15–65	5,000	North 45° west.	75	do	Do.
7. 89 vein	do	3	350	do	83	Quartz and manganese.	Do.

5. The Nancy No. 1 vein is composed of honeycomb quartz and manganese oxide, forming a well-defined banded structure, and the hardness increases with depth; it contains much calcite below.

6. The Nancy No. 2 vein which is the biggest one in this district can be traced over 5,000 feet and the values, as a rule, are found near both walls for a width of 10 to 35 feet. This vein is also composed of quartz, calcite, and manganese oxide, and the calcite content increases with depth.

7. The 89 vein which is a very narrow streak carrying extremely high values is composed of rather softer quartz with a little limonitic mud and manganese oxide, and it contains no calcite.

The ores from these veins are suitable for the cyanide process, containing very fine particles of gold.

The ore is received from the mine by means of a gravity tram with 2¼-ton cars and by a mill level adit; and delivered to a 65-ton storage bin. From this bin it is fed by gravity to a trommel washer with a 40-inch diameter by 16-foot mixing chamber running on tires and rollers and driven by a rope drive through miter gears and spur and pinion on washer at six revolutions per minute. The washer is lined with plain half-inch curved iron plates and has two flights of spirals made of heavy angle iron to promote discharge of the ore. The trommel is slightly conical the same size as washer and 5 feet long. It is punched with half-inch round tapered holes.

Water is introduced with the ore in the washer partly at the feed end and partly at the discharge as a high-pressure spray thoroughly to wash the ore and free it of clay and slime. The fines discharge is led by a launder to a Dorr duplex classifier which is set to discharge practically all minus 200-mesh slimes. The sands from this classifier are dragged forward and discharged to the tube mills, entering the regular cyanide circuit. The slimes are led to a storage tank and fed to an 8-foot Senn Batea pan amalgamator running at 175 revolutions per minute with

a ⅝-inch motion. This feature is somewhat of an innovation and was made necessary by the fact that the ore contains an unusually high percentage of clay and slime that prevents it from settling in the thickeners. Before the Senn table was tried the settling and filtering capacity was not nearly equal to the grinding capacity of the mill, the slime at times requiring over 20 square feet of settling area per ton as compared to about 7 feet for free settling slimes. Since the table has been in operation the settling and filtering capacity is equal to the grinding capacity and has shown an increase of 70 per cent. Extraction on the Senn pan is very low as would be expected due to the very fine state of the gold that passes over the classifier and to the fact that this gold is contained in all the clay and slime washed out of the total ore received. However, only about 10 per cent of the tonnage passes over the Senn and the heads are very low due to the extremely fine classification; so that the total loss per ton is low and is many times compensated for by the large increase in tonnage and a saving in cyanide and lime necessary per ton milled as well as an increased extraction in the cyanide circuit.

The washed oversize from the washer trommel goes by means of a 16-inch belt conveyor to a storage bin for the crushers, discharging on a 5-foot by 8-foot grizzly with ¾-inch spacings; the oversize going to the crusher bin and the undersize to the ball mill bin. The coarse ore is fed to a 10-inch by 16-inch Blake type crusher set at 1½ inches and running at 230 revolutions per minute. The crusher product goes to a set of 16-inch by 36-inch D. E. W. Co. rolls set at ¾ inch; the product from the rolls going by means of a 14-inch belt and bucket elevator to the ball mill storage bin. The elevator discharges into a small grizzly with ½-inch spacings and the undersize goes by a conveyor belt to a fines storage bin from whence it is fed by a revolving disk feeder to the Abbe tube mill whenever the load of sand will permit.

From the ball mill bin the ore is fed by means of a 30-inch revolving disk feeder to a 16-inch by 6-foot Hardinge ball mill running at 25 revolutions per minute; sufficient solution being introduced for dilution to about 30 per cent moisture. The ball mill discharge, all of which is minus ¼-inch mesh, is elevated by means of Frenier sand pumps (10-inch by 54-inch) to two Dorr duplex classifiers, the slimes going to two 30-foot Dorr thickeners and the sands going to one 60-inch by 6-foot Hardinge pebble mill and one 6-foot by 16-foot Abbe tube mill. The discharge of these two mills is elevated by the Frenier pumps to the two Dorr classifiers, and the classifiers return the sands to the mills and the slimes to the thickeners.

From the thickeners the thickened pulp is conveyed by diaphragm pumps to three 30-foot Dorr type agitators placed in series. The pulp from the final agitator goes to three Kelly type filters. The filters are loaded by a 6-inch Byron Jackson sand pump and the cake formed in from seven to ten minutes by means of a montejue and an air compressor at 45 pounds pressure. After the cake is formed, the excess pulp is returned to the agitator and barren solution introduced into the filters from a storage tank through a 5-inch Goulds centrifugal pump at 35 pounds pressure for a period varying from thirty to sixty minutes and dependent on the tonnage being handled. After the barren wash, water is introduced and a wash of two to five minutes used. The filters are

then run out and the cake sluiced to waste. The filter cycle ordinarily takes two hours.

The total effluent solution from the filters is pumped by a low speed centrifugal to No. 6 thickener and clarified by settling, thence it goes to the mill solution pump and is elevated by a 7-inch by 8-inch Goulds triplex pump to the mill solution tank, forming the solution used in the grinding and classifier circuit.

The clear overflow from the thickeners goes to a 15-foot fiber clarifier, thence to a 15-foot sand clarifier, and thence to five 6-compartment zinc boxes where the values are precipitated. The barren solution from the zinc boxes is elevated by a 7-inch by 8-inch Goulds triplex pump to a barren-solution storage tank at the head of the mill whence it returns to the filters for the barren-solution wash.

The zinc boxes are cleaned and dressed weekly, and the resulting shorts and precipitates are roasted and dried; fluxed and smelted in a No. 275 "Case" tilting furnace and the bullion shipped to Manila offices.

The present capacity of the mill under proper operating conditions is about 200 tons per 24-hour day. Owing to extreme variations in cost of materials and supplies no milling costs can be given as they are so variable as to be of no value.

Power is furnished by two 150-horsepower Mirrlees Diesel engines and one 165-horsepower Busch-Sulzer engine: all direct connected to direct-current generators, generating current at 110 volts. Motors are used for all drives and the average power consumption at present, including one 35-horsepower air compressor making air for the mine, is from 2,000 to 2,100 amperes.

The Colorado Mining Company.—The Colorado mine was discovered, very soon after the American occupation, by Mr. Herbert, and ore from it has been milled fairly continuously since 1911 until it closed down this year (1922). To Mr. Lloyd Robert, the superintendent, I am indebted for the following description of this property:

The Colorado mine exploits a number of lodes on Bagadilla Mountain, of which No. 5, Sub 2, 8, and 9 are the most important. All of these are parallel in strike, and all except the Sub 2 in dip. Sub 2 vein dips in the opposite direction.

In addition to these, there are a number of veins intersecting No. 5 vein, and usually called split veins. Of these the 7 Split, the Split vein, and the Tabios Split are the most important. These, in general, carry narrow veins of higher-grade ore.

No. 5 vein has been the most important of all veins and has been opened for a length of 2,300 feet and depth of 800 feet. In places it has had widths of 30 feet in pay ore.

All the main lodes are cut by a fault which has a right-hand throw of 65 feet. A number of parallel smaller faults are known but the dislocation in these is small.

The vein filling is quartz, in parts carrying considerable manganese. Practically no other metals occur, and no sulphides are found. The gold is rarely visible, and the ore is not free milling in any profitable per-

centage. It is, however, readily amenable to cyanide treatment. The values are extremely spotty but the range is not great, anything over 50 dollars being exceptional.

The ore is passed over a grizzly with 2-inch opening and oversize is crushed and stamped in three batteries, of 1,250-pound stamps. The crushed product, together with the grizzly undersize, passes to a ball mill, 5 feet by 6 feet, and thence to two tube mills in close circuit with two Dorr classifiers. The undersize from the classifiers, of which about 90 per cent will pass a 100-mesh screen, goes to a Dorr thickener, 14 feet by 28 feet. The thickened pulp goes to two Pachucas in series and thence to an 81-leaf Butters filter. The overflow from the thickener is passed into two more Dorr thickeners which act as settlers for the almost clear solution, and they, in turn, overflow to a small sand filter clarifier and thence to the zinc box supply or gold tank. An average of 350 tons of solution is precipitated per day.

Cyanide consumption averages 0.65 of a pound per ton, and zinc about the same. Lime, 15 pounds per ton; strength of solution 1.5 pounds per ton, KCN, and 1.3, CaO. Tube mills use mine rock, and require 20 to 30 pounds of rock per ton of ore. Ball consumption 2 pounds per ton.

Accurate drip samples are taken of zinc-box flow, and flow is measured by a Bristol recording gauge. Heads are calculated from the value precipitated per ton and the filter tails. They are partially checked by a rough and unsatisfactory sample taken above the batteries.

Many improvements have been made in this district in late years; chief among them are a new road from Aroroy to the southernmost large mill, the Syndicate, and a branch from this road to San Agustin Bay, where landings have been made for the Colorado and Syndicate properties. There is now an excellent steel bridge over Lanang River, as well as a schoolhouse on the Colorado property for the children of the mining population. There are also churches and cinematograph halls. Boats between Manila and Aroroy ply with greater regularity than formerly, and there is telephone and telegraphic communication. The district seems to be in excellent condition, and prospects are very promising for successful operations on some of the properties for some years to come. There are many veins on the properties of the two operating companies, as yet unprospected, which may prove to be of workable value.

THE BAGUIO DISTRICT

The heart of the Baguio mining district (Plate 15) is situated less than 8 kilometers east of the former summer capital of the Philippines, from which it gets its name. It lies about 270 kilometers almost due north of Manila near the southern end of the great Cordillera Central. The elevation varies from 900 meters at Antamok to over 1,500 meters on the surrounding

A railroad has been projected to connect Aringay and Baguio; some of the grading has been done; from Baguio wagon roads will terminate at the several properties. At present there is an automobile road about 14.5 kilometers up Bued River Cañon from Damortis, near the northern terminus of the Manila Railroad.

This is a region of high relief and great erosion due to torrential precipitation. Pine is the dominant tree, but it is growing scarce in the vicinity of the mines.

Water is the chief source of power, but larger installations are needed than are available at present.

American miners have been prospecting in this district for fifteen years, but only during the years 1908 to 1911 and 1915 to 1921 has successful mining been carried on by organized companies. In 1909, there was a severe typhoon, which wrecked the Benguet Consolidated mill, and in 1911 the district suffered other setbacks, so that there was practically no production from 1911 to 1915. One 3-stamp mill continued milling rather steadily throughout much of that interval, and in 1914 the Benguet Consolidated Company rehabilitated its plant and is to-day operating very successfully. Several of the properties that were once well known in the district and gave some promise of realizing a future, have for the time being at least become negligible features. These are the Acupan, the Bua, the Major, and the Headwaters. Other prospects, such as the Muyot and the Kelly groups, are expected to become mines some day; but so far only development work has been done on them. Others, from which some people have hopes of realizing fortunes, will probably never come to fruition.

Prior to American occupation, the veins of this district had been worked by Igorots, Filipinos from neighboring provinces, and Chinese. Some of the old workings are rather extensive and have been of great help to prospectors in locating veins. They are similar to the workings found in other parts of the Islands where only the rich stringers were gouged out and are, consequently, so narrow that an American would find it almost impossible to go through them. One of the drifts in the Kelly mine cut an old Igorot stope filled with waste that had become cemented as hard as the wall rock.

Geology.—The geology of this district, has been described by Eveland, (237), by Eddingfield and Smith, (603) and by Dickerson.*

* Philip. Journ. Sci. **23** (1923) 413–453.

The last-named author deals largely with physiography. Eveland was the first to make a systematic geologic reconnaissance of this region, and the essential results of that survey have been corroborated by later work.

The principal formations in the Baguio district are quartz-diorite and granite intrusives, some Tertiary sediments, andesite flows, tuffs, and agglomerates. The oldest sedimentary formations in this area appear to be the Vigo group, conglomerates, sandstone, shales, and limestone of middle Miocene, which are exposed at places well down in Bued River Cañon, and in Major and Copper King Creeks. These are cut by both andesitic and quartz-diorite intrusions, and in the southeast end of the area the latter is cut by a hornblende granite. Above the whole, stratigraphically, and in some places actually superimposed and in contact, is the later andesite consisting of solid and agglomeratic flows. In the western part there is, overlying all of the foregoing, the Malumbang limestone of Pliocene age. Following the folding and intrusions, which began probably with the Miocene but which culminated toward the close of the Miocene and continued into the Pliocene, extensive mineralization and vein filling took place with quartz, calcite, and manganese as the chief gangue minerals, carrying gold and silver with, possibly, some tellurium, and small amounts of mercury in some places. This deposition of silica and calcite continued through the Pleistocene, and has not altogether ceased even now. This region, like most parts of the Archipelago, is profoundly faulted and fissured. Not only were all the fissures of the country filled, but much of the overlying andesite and tuff were silicified by the siliceous solutions, giving rise to the especially characteristic Baguio formation which is well shown near Government Center in Baguio City.

The Benguet Consolidated.—The Benguet Consolidated mine (Plate 33) is the richest gold mine in the Orient. It is located in Antamok Valley, about 12 kilometers southeast of Baguio. To the president, Mr. A. W. Beam; the superintendent, Mr. O. L. Kettenbach, and Mr. M. F. Dodd I am indebted for the following information about the property and its history:

> In 1902, Mr. H. Clay Clyde discovered this bonanza. Like the majority of discoverers of payable mines, however, Mr. Clyde realized almost nothing from his find. He, together with Messrs. M. A. Clarke and Nels Peterson, organized the Benguet Consolidated Mining Company a year later. The first plant, which consisted of three stamps, amalgamating plate, and leaching tanks, with a capacity of 25 tons per day, was erected by Mr. Clyde M. Eye, E. M., in 1905. Gradual additions were made to the plant so that,

four years later, the company boasted of six stamps and sufficient additional equipment to increase the handling capacity of the plant to 40 and 50 tons of ore per day.

In 1909, the flood at Antamok, Benguet Province, where the mines are located, destroyed the cyaniding portion of the plant. Mr. Nels Peterson repaired and placed in commission the milling section of the plant the following year, and it was operated by him until the latter part of 1911, when the remaining portion of the plant was swept away by flood.

For the purpose of building a modern, up-to-date milling and cyaniding plant with a capacity of 50 to 60 tons per day, sufficient capital was raised locally during 1914, and Mr. Eye returned to supervise its erection and to remain as operator. Since the erection of the present plant, the operations of the Benguet Consolidated Mining Company have been very successful. The handling capacity of the plant is now from 120 to 130 tons of ore per day. Shareholders in the Benguet Consolidated receive regular quarterly dividends of 50,000 pesos and an additional 50,000 pesos in July and January of each year.

The developments underground are now so satisfactory that plans are under way to enlarge the plant so that it can handle 175 tons per day. Production will then increase to 1,500,000 pesos per year. Over 1,000,000 pesos worth of gold bullion was produced by the Benguet Consolidated in 1920.

The Benguet Consolidated Mining Company is a *sociedad anónima* organized under the laws of the Philippine Islands in 1903. The present capital of the company is 700,000 pesos, Philippine currency, divided into one million shares of a par value of 70 centavos each. The original capital of the company was 1,000,000 dollars, but this was reduced to 1,000,000 pesos in 1916, and on March 25, 1921, the capital was further reduced to 700,000.

The company owns approximately 420 acres of mineral-bearing land, of which 285 acres are held under patent, and 135 acres under location. Its holdings cover about 8,000 feet along the strike of the main Benguet lode.

From the commencement of operations in 1906, until the end of 1920 we have mined and treated 143,793 tons of ore, of an average value of 38.50 pesos per ton, at a saving of 90 per cent of the gold and silver content, or a total saving of 4,983,750.62 pesos, Philippine currency. During 1920 we treated 35,565 tons of ore at a production of 1,068,892.30 pesos, Philippine currency, and a net profit of 456,668.58 pesos.

Total dividends paid to the end of 1920 amount to 1,250,000 pesos.

*Estimate of ore reserves, January 1, 1921.**

	Tons.	Pesos.
Positive	27,100	860,000
Probable	38,810	1,417,840
Possible, exposed incompletely on one side	67,000	2,370,000
Total	132,910	4,617,840

* On January 1, 1922, the ore reserves were estimated at 142,410 tons, value 5,782,124 pesos.

Since the foregoing ore estimate was made we have cut the foot wall vein on Level "C," thus bringing into the "possible" column a large tonnage of ore not counted in the estimate.

In connection with the ore estimate it is interesting to note the production from Level "B," which is approximately 120 feet on the dip below Level "A." Exclusive of ore taken from Level "B" through the old mine, the amount of which was considerable but unknown, Level "B" has produced 59,212 tons, and still contains in positive, probable, and possible ore 42,910 tons, or a total for this level of 102,122 tons. The pay chute opened up on Level "B" is more than 1,400 feet long, with high values in the face of the drift west on the hanging wall vein. This drift has been discontinued for the reason that it is near Antamok Creek and not far enough below the creek to make it safe to continue.

The ore is a mixture of quartz, iron sulphide, altered diorite, and clay, with quartz predominating. Although a very small percentage of the gold is free none is visible. The ore treatment consists of crushing, stamping in cyanide solution, grinding in pebble mills to pass 100-mesh, and a nine-day cyanide treatment. The pulp is passed through an Oliver filter before final discharge.

Electricity is used for power and lighting. It is furnished by two small hydro-electric plants having a combined capacity of 375 K. V. A.

The geology of the mine, as described by our mine superintendent, Mr. O. L. Kettenbach, in his last annual report, is as follows:

"The main Consolidated vein is formed by two main fault fissures and a third series of adjustment cracks, formed, I believe, with one exception, contemporaneously with the second of these main fissures.

"In the first two fissures were deposited the main hanging wall and foot wall veins. Of these two the hanging wall vein is by far the older, non-mineralized inclusions being practically absent within it while abundant in the foot wall vein. The fault movements producing both fissures were intense, as is evidenced by the cleanly defined hanging wall of one and foot wall of the other, together with the abundance of clay selvage on both and the intensity of slicken siding which is occasionally seen.

"The advent of the footwall fault in such close proximity to the hanging wall fault created a zone of weakness beginning at the former and extending to the latter. Adjustment cracks and planes always follow major fault movements and I take the numerous cross veins in the mine to have been formed in cracks or secondary fissures caused by these movements. * * *

"These two fault systems are by no means parallel, and the mineralized solutions working along each produced, first, a zone of enriched ore in close proximity to each fault plane, and, secondly penetrated the brecciated mass lying between the two and mineralized it in a ratio varying directly with the distance separating the two fissures.

"The remarkable persistence of values, both laterally and vertically, particularly in the hanging wall fissures, leads one to the belief that the mineralizing solutions were at least fairly deep seated and abundant in their supply."

At present (March, 1921) the company is driving a 3,500-foot drift along the hanging wall of the lead, the entrance to this being in Antamok Cañon to the east of the present workings about 3,500 feet. This is primarily intended for drainage, but it will also be used thoroughly to prospect the lead by means of crosscuts and raises run from it at regular

intervals. The old native workings, known as the "Fianza gold mine," are included in the ground to be explored by this drift.

The old mill and the process as used at the Benguet Consolidated mine have been fully described.* The flow sheets for the present mill are shown in figs. 21 and 22. The capacity of the

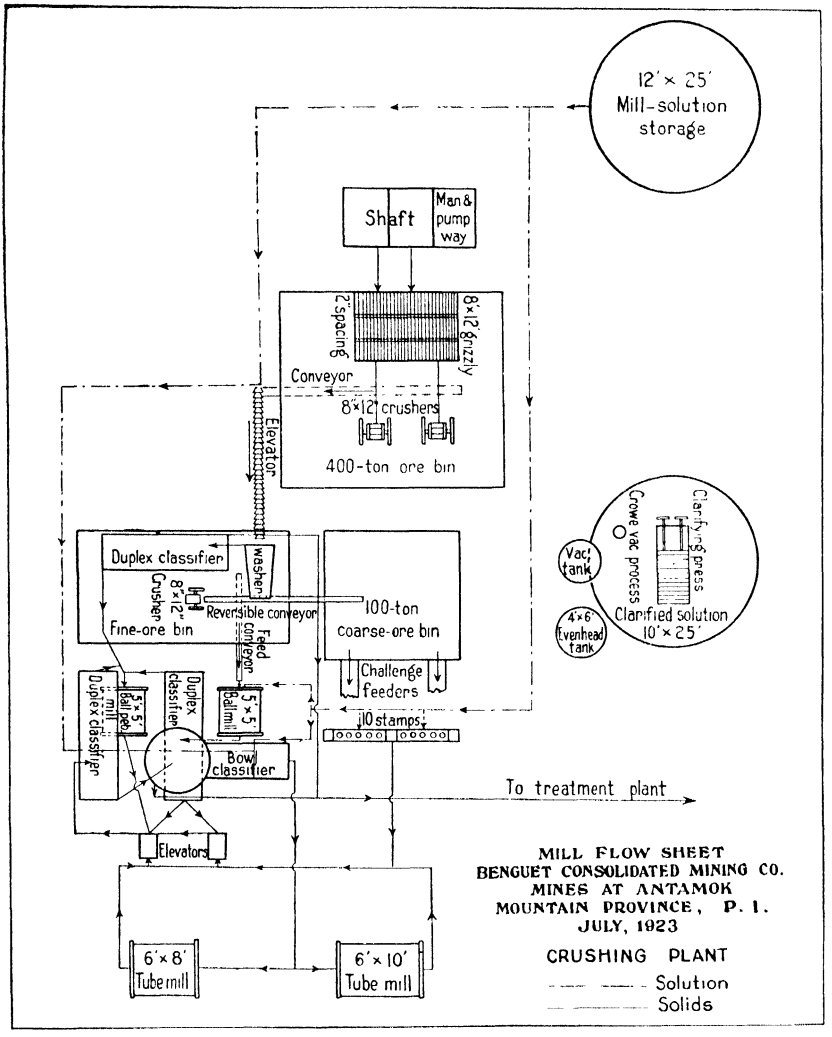


FIG. 21. Mill flow sheet of the Benguet Consolidated Mining Co.; crushing plant.

new mill is 250 tons daily. The crushers are Joshua Hendy Hercules type 8 inches by 12 inches. Their individual capacity

* Mining & Scientific Press (December 4, 1920).

is 100 tons daily of coarse rock to 1 inch. Ball and ball-pebble mills are of Allis Chalmers make. The former reduces 175 tons daily of 1-inch feed to $\frac{3}{16}$-inch product. The latter reduces 60 tons of about $\frac{3}{8}$-inch feed to sand. Stamps are Joshua Hendy make. They weigh 1,050 pounds each and drop 106 times per minute. They are run intermittently only. Their

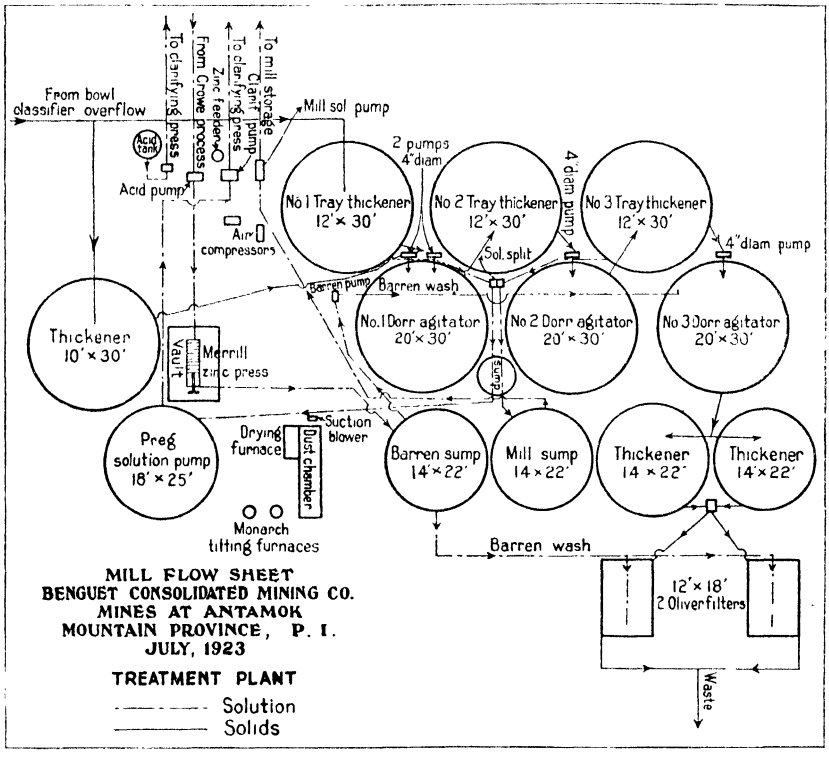


FIG. 22. Mill flow sheet of the Benguet Consolidated Mining Co.; treatment plant.

full-time capacity is 50 tons of 1.5-inch feed through a 0.5-inch screen. The tube mills are of Denver Engineering Works make. Combined they reduce about 100 tons daily from $\frac{3}{16}$-inch feed to 92 per cent 100-mesh discharge. The Crowe process and precipitating machinery is by the Merrill Metallurgical Co. Its capacity is 600 tons solution daily. Thickening and agitating machinery is of Dorr Co. make. Filters are made by Oliver.

The Bua mine.—This property is situated just across the river from and below the Benguet Consolidated mine.

In 1909 this mine and mill were in full swing and gave promise of becoming a real producer, but since the typhoon of

October, 1909, the property has not been operated. The Bua property before it closed down was working two veins at Gomok, one a quartz vein from $\frac{1}{3}$ to 1 meter in width, the other a rhodochrosite vein 1 to 2 meters wide striking north 10° east and dipping 65° to the south. There were several hundred meters of underground workings in this mine and a well-equipped mill. At the present time everything has been abandoned.

The Headwaters mine.—The Headwaters property on the upper Antamok had a fairly elaborate equipment, consisting of stamps, tube mills, Pachucas, and a Ridgeway filter; unfortunately it had three serious handicaps; namely, insufficient ore, very little timber, and lack of cheap power. The failure of this company gave a severe setback to the district. At the close of 1921 development work was resumed on this property.

The Camote-Clayton.—The Camote, adjoining the Benguet Consolidated property on the southeast, is one of the largest ore deposits in the district and seems to be a continuation of the Minnesota lode, on which the Benguet Consolidated mine is located, as well as of the well-known Fianza ore body between the two. The vein where it is opened on the Camote property is manganese and calcite and is said to average about 8 meters in width. A large amount of ore has been developed and between 500 and 600 meters of workings have been driven. This ore is said to "catch 6.50 dollars on the plates alone." Mr. Reavis operated a small mill here for a time, but this has been abandoned.

The Kelly group.—The late J. E. Kelly developed through a long period of years a group of claims near the head of Gold Creek, just west of the Benguet Consolidated property. This group on the north slope has four veins: No. 1 particularly shows as a strong high dike on the bank of a stream; No. 2, north 60° west, dipping 60° to the north; No. 3, south 60° west; and No. 4, north 34° west; the outcrops of these veins are well marked. Considerably more than 1,000 meters of drifting and crosscutting has been done on the veins which vary in width from 1 to 3 meters. The values, while encouraging in spots, are not consistent. The ore carries no free gold, but has more or less telluride. On the south slope Mr. Kelly had cut four more veins with from 500 to 1,000 meters of workings. These veins generally run east and west and vary from 0.6 to 10 meters in width (fig. 23). About half the gold in this group is free milling. These properties might be worked in consolidation with others, but alone they present some difficulties.

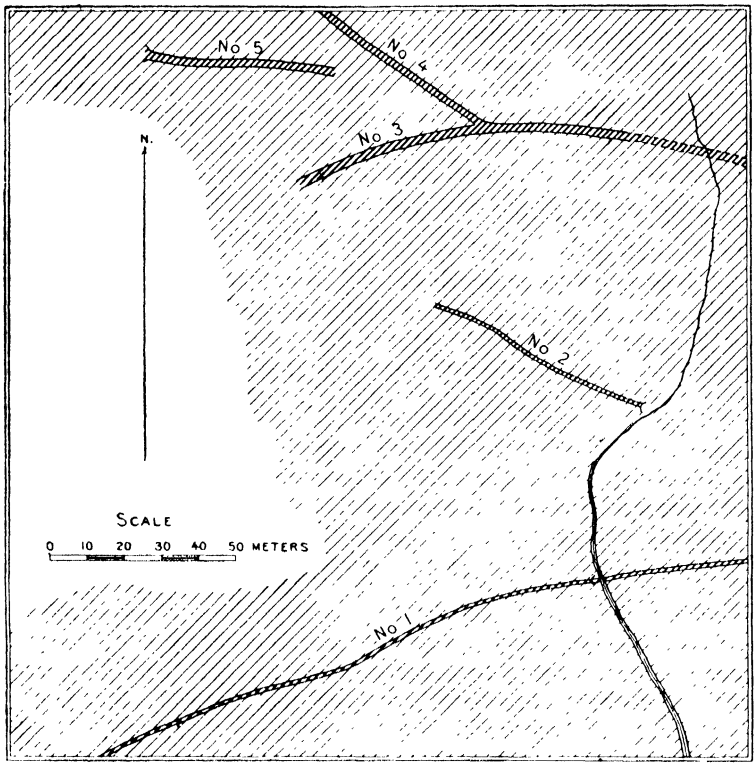


FIG. 23. Gold veins on the Kelly property.

Other groups are the Major, Lorenzo Pau, Antamok Valley, and Muyot. As most of these are on veins which cut the upper andesite, they will probably never prove as valuable as those located on or near the contact of the quartz diorite and older andesite of Antamok Valley.

Acupan.—There is a group of claims located north of the barrio of Acupan, on Batwaan and adjacent creeks, which have been developed for some years. During 1915 and 1916 there was a small 3-stamp mill operating, but this has since been shut down.

I examined this property very recently (June, 1922) and do not hesitate to say that it is at present the most promising and nearest to development of any of the properties in the district not now operating. Besides a considerable amount of ore already developed, its main vein, a true fissure vein in the diorite, promises to be persistent and to yield good values with depth. Fair power can be readily available. The tenor of the ore is

about 16 pesos in the body above water level. It should improve with depth.

Demonstration.—This mine is located on the old Copper King group of claims and is being developed under the direction of Mr. H. P. Whitmarsh. There are two veins which lie close to the contact of andesite with Tertiary sedimentaries. One of them is a quartz-calcite-manganese vein, and the other is refractory, carrying copper, lead, and zinc. A 5-stamp demonstration mill has operated for a time on this property; hence the name.

The Ascension group.—Nothing further has been done on this group since the regrettable murder of Mr. Calvin Horr by an Igorot, in 1918.

The Magma.—On Dunglay Creek, in the extreme southeastern corner of the Baguio district, about 1 kilometer from the barrio of Acupan, is one of the largest bodies of quartz I have seen anywhere in the Philippines. Unlike most of the veins in this district, this one strikes nearly due north and south and dips to the east. Mr. H. P. Whitmarsh, who has for so long been a prominent figure in Benguet mining, is developing this property and reports very encouraging assays. Mr. J. D. Highsmith discovered the lode. The country rock is quartz-diorite, which a later granite has intruded. The property gives every promise of a bright future.

OTHER DISTRICTS

Palidan Slide, Suyoc.—This is an enormous slide in more or less soft, decomposed, mineralized diorite and andesite which the Igorots have panned for gold for years untold (Plate 21). Several Americans have from time to time worked the stringers in this slide, and for a time Mr. Gillies treated the ore in an arrastre.

Igorots are reported to have taken out from 40,000 to 80,000 pesos worth of gold in a single season. The method is similar to that employed in other countries, and is known as "booming."

Several quartz veins, none very wide, are being developed at several places near Suyoc, the best looking of which appears to be the one at Dugong, about 3 kilometers west of Suyoc. I secured some exceptionally rich hand specimens in May, 1922.

Binalonan, Pangasinan.—Mr. Geo. Mentzer has operated a small stamp mill intermittently in this locality for some years, but with only nominal success.

PLACERS

The principal gold-bearing alluvial areas in the Archipelago are Paracale and adjacent rivers from which the cream has

been taken, on the north coast of Camarines Norte, and the east coast of Mindanao near Lianga. The last-named areas are being dredged, or preparations to dredge are being made, at the present time.

On Binabay River, Mindoro, some gold placers have been prospected from time to time with indifferent results.

In past years there have been attempts, some successful, many not so, either to dredge or to sluice along Iponan and Cagayan Rivers in Misamis, along the Cansuran in northeastern Mindanao, along Lanang River in Masbate, along Agno River in Pangasinan, in Nueva Ecija, and at several points on the east coast of Luzon.

Placer types.—Philippine placers are of two general classes; namely, high-level, or bench; and low-level, or those in the valley bottoms, whether occupied by running water or not. No beach placers, as far as I know, exist in the Philippines.

Origin.—Philippine placers, like placers in other parts of the world, have originated from the erosion of lodes somewhere on higher ground, either near or distant.

Age.—All the placers that have been dredged in the Philippines are, without much doubt, the result of erosion since the last great uplift in the Archipelago; that is, since the Pleistocene.

Values.—In the early days of the boom in Paracale, about 1910, some ground was found to run as high as 2 pesos per yard, while the average was 25 centavos.

Placer districts.—In addition to the placer areas already mentioned in connection with Paracale and Aroroy districts, the following more or less well-known fields either have been prominent in the past or promise to merit some serious interest in the near future:

Near Peñaranda, Nueva Ecija.
Umirey River, east coast of Luzon.
Cagayan and Iponan Rivers, Misamis, northern Mindanao.
Cansuran River, northeast Mindanao.
Lianga, east coast, Mindanao.
Binabay River, Mindoro.
Placer, Surigao, Mindanao.
Curuon, Zamboanga Peninsula, Mindanao.

Of these only the Lianga is being worked on an up-to-date scale to-day.

Peñaranda.—The gold placers of Nueva Ecija have not received much attention, although they have been known and worked for sixty years or more by foreign capital.

It is reported * that a Spaniard, fifty years ago, worked placer ground at a point about halfway between Cabu and Peñaranda on the Sapang Bujoy. A map of Luzon, by d'Almonte, published in 1883, has marked upon it six points in this district where gold had been found, one on the Sapang Bujoy, two on the Macabaclay, two near the junction of the Rio Chico and the Sumagbac, and one near the head of Santor or Cornell River.

An Englishman about 1890 did some work near the head of Cabu River at Bakas. At that time also, a company was formed in Manila which started work on the Macabaclay with a crude sluice. Its operations were terminated by the insurrection of 1896 and no more work was done until Mr. Dorr, who had been employed by this company, resumed work in 1905.

No other records of work done by white men previous to 1909 could be found; but Filipinos have worked the gravels for ages by hand panning and hundreds of them at present have no other occupation.

A number of men from Manila formed a company in 1909 and located claims on almost every stream between Cabu and Gapang. They tested the ground near Peñaranda with a boring machine. These boring tests were reported as showing 33 centavos per cubic yard. Pan tests in other localities gave much higher values, ranging from 50 centavos to 1 peso. Such ground when worked on a suitable scale will give good returns on the money invested.

One of the most interesting features in all parts of this region is the presence of platinum in small quantities. Filipinos were ignorant of its value and always threw it away when they separated it in their pans. It is probable that iridium or other rare metals may also be found, as stated by Goodman. The only other region in the Philippines where platinum has been encountered is at a point about 64 kilometers south of the Nueva Ecija district, and the indications are that both deposits are derived from the same source.

The gold is bright yellow and is reported to be 958 fine. It occurs almost invariably in thin disks or flakes, varying in size from a fine dust to rare fragments as large as a 10-centavo piece; it averages about 0.5 centimeter in diameter. This would lead to the assumption that the gold came from a schist or gneiss, or a much-squeezed quartz vein. The only rock of this character so far reported in this region is the gneiss mentioned by Goodman, but extensive exploration has never been made.

The area in which paying amounts of gold can be found is very large, extending from the eastern cordillera to the Rio Grande de Pampanga, between Santor River and a line 8.4 kilometers south of the Rio Chico, about 1,550 square kilometers. There is a bed of sand and gravel which seems to cover this entire area, possibly produced by constantly shifting streams. This explanation of the origin seems more probable because of the

* From notes by Goodman.

great number of streams which seem to head from about the same source in the eastern cordillera, all of which carry gold even to their mouths. These streams are the Rio Chico, Ilog Munti, Sapang Palanao, Cornell or Santor, Mayon, Macabaclay, Pagsanjan, Calabasa, and Cabu, which flow into the Rio Grande.

Umirey River.—For notes on this field we are indebted to Judge Frank B. Ingersoll, who has been prominent in dredging circles for many years in the Philippines.

This is a region almost entirely unexplored during the Spanish régime. It has only been within the last ten or twelve years that it has been invaded by the American prospector. Unlike most of the gold-bearing districts of the Philippine Islands, the native inhabitants in this region know practically nothing about even the most primitive kind of mining. In most localities of the Archipelago where gold is found the natives know its value and how to win it from the rock or the alluvial dirt. Many of them, particularly the women, are very skillful panners. Along the Umirey and its tributaries there are never seen either wooden *pabirics*—so well known elsewhere—or any other gold-saving devices.

The people are very primitive in their habits. Up to the last few years they had no fixed habitations and depended for food on fishing, hunting, and trapping. Of very recent years a few of them, under the tutelage of the American prospector, have settled down, built houses, and are cultivating a few crops.

The people are called Damagats (?). Most of them are tall and powerfully built, being capable of "packing" tremendous loads over the mountains. They are reputed to be the descendants of Spanish residents of a penal colony who mated with diminutive Negritos, from which alliance come their "kinky" hair and dark complexion.

Up to the advent of the American prospector about 1911, most of these people had never seen money and the "cargadores" (packers) were paid in red cloth, beads, small mirrors, salt, etc. This occurred in a district not much over 30 miles from Manila in an air line.

So far as it is known for gold possibilities the district is located in the two provinces of Rizal and Tayabas. The Angelo River, which is a branch of the Umirey, rises in the northeastern part of the Province of Rizal near Mount Angelo. This is in the sierra which divides the Pacific slope from the rest of the Island of Luzon. The Angelo is a branch of the Umirey, which latter empties into the Pacific Ocean at Dingalan Bay about 80 miles to the north of the port of Mauban.

The Angelo and the upper part of the Umirey run through extremely rough country and the current is very swift in most places. Here and there level stretches are encountered where there are flats suitable for dredging. This condition obtains for about 35 miles. Over much of the distance there is little but exposed and barren bed rock. At one place the Umirey River disappears from view and runs underground for a distance of about three miles. Shortly before reaching the comparatively low lands through which the Umirey runs for about 18 miles before reaching the sea, the river descends through a succession of cataracts. Here the country is so rough that it is with great difficulty that an ascent can be made on foot and the cost of a road would be prohibitive.

For a number of years, the Luzon Gold Company, a Philippine corporation, has had large placer holdings along the Angelo and the upper reaches of the Umirey. In places there are most excellent showings and as a rule the gold found in the streams is coarse. At one place there are large flats, physically well-suited for dredging, with an estimated gold-bearing area of about 600 or 700 acres. At other places the ground is suitable for hydraulicking and still again for ground sluicing. As yet there have been no discoveries of veins.

In 1912 a small sluicing plant was installed on the ground below the cataracts of Umirey River, but this was swept away by a freshet and the gold in the sluice boxes, estimated to be worth about 10,000 pesos, was lost.

The dredging ground mentioned has had considerable testing and its owners estimate very high values, but to bring in the necessary plant would require the building of a road through the mountains for a distance of about 48 kilometers from the town of Montalban, Rizal Province, which is about 32 kilometers distant by rail from Manila.

On the lower Umirey River, Messrs. Squires Brothers, of Manila, have a number of dredging claims. Several years ago, an Australian company, Umirey Gold, Ltd., built a dredge near the mouth of the river and, partly by flotation and partly by digging a channel, worked its way up the river for some 24 kilometers to the Squires Brothers's claims which had been taken under a working lease.

There has been a great deal of discussion regarding the adaptability of this dredge to the conditions encountered and the methods used in attempting to win gold. At all events the venture was unsuccessful, and the dredge was finally dismantled and moved to the Lianga district in Mindanao.

Cagayan de Misamis, etc.—Enrique Abella(1) published a lengthy account of this district as early as 1877. A translation of his Spanish report will be found in the Mineral Resources for 1909. In 1908 Ickis(335) made a survey of portions of the same country.

The principal workings of the people of Misamis were located along the Iponan and Cagayan, near Pigtao on the former and Manigue on the latter stream. The placers are of two general types; the high-level, or bench, placers of greater age, and those of the more-recent river bottom. Ickis was of the opinion that in spite of the values in gold which the Filipinos had recovered from these streams modern dredging or large-scale sluicing in these localities would hardly pay; but over the divide, on the headwaters of the Pulangi to the southeast, he found extensive

gravel beds which yielded such encouraging panning tests that he recommended further exploration with drills.

The gold in this region, like much of that in northeastern Mindanao, is clearly derived from quartz veinlets in schists. Accompanying these schists in this region are some old slates, which may be of Mesozoic age.

The following paragraphs are excerpts from a translation of Abella's description of these early workings, particularly of the bench placers:

> Not all the gold is won from the sands of the river bottom, and they have recourse to them, as I have already indicated, only in the dry season, during which the bench placers within the limits of the hydrogeologic basin of Iponan River cannot be worked.
>
> *Situation.*—From the village of San Simon, where the valley walls are higher and more confined by rounded hills, the river receives as one goes upstream a great number of tributaries which cross many alluvial and auriferous spots and also unimportant arroyos. For example, following the river upward, there is, on the left, the small valley of Pasayanan, with indications of scattered and ancient workings; then, on the right, the richest, that of Batinay, which moreover is of greater extent; then that of Dominalog with recent workings of a less-primitive character; and continuing, those of Babantohon, Pigsagan, Dumalogdog, and the famous Pigtao, the locality where the most remote Christian settlement, now withdrawn to Tagsulip, was established; and finally, Camingañan, Cayomangon, Saganahai, Tapbagbag, and Taculut, almost within the territory of the Moros.
>
> *Continuity.*—The placers are not all situated on the same level as the waters of Iponan River, but at a certain altitude above them, not exceeding as a rule 20 meters, and in elevated parts of the lateral branches, though never very far from the principal river, demonstrating that the origin of the placers bears a definite relation to the ancient bed of the stream. This bed, formerly very much wider than the present one, has suffered with time from the effects of partial denudation which has eroded the once continuous capping of the alluvions, resulting in the present discontinuity and isolation of these localities.
>
> *General character of the placers (alluvions).*—The general character of the alluvions is uniform. Essentially argillaceous throughout, it is in the upper part composed of a very sticky clay, reddish, and containing very small rounded pebbles, fragments of old slates of various classes, which become more numerous and larger as one goes deeper, the clay which envelops them being usually whiter, more sandy and not so compact, and containing pebbles (cantos) of eruptive rocks, others of magnetic iron or hematite, which the natives call *tonasé*. The abundance and size of these pebbles are considered a sure indication of the richness of the placer. The gold is not confined exclusively to the portion in which the pebbles are found, since in the uppermost layer of the alluvion gold dust begins to be encountered, although rather scattered; but, nothwithstanding this dispersion of the gold, most of the metal, the greater richness, is always found near the bed rock. The depth of one of these placers never exceeds 7

meters in those places where it has its greatest area, nor does it become less than a meter in the smaller areas, this difference being due to the subsequent denudation to which I have alluded above. In those spots where this process has had little effect and where the alluvions are intact, the natives distinguish in them various horizons which really correspond to the changes of composition and appearance I have already pointed out, and distinction and classification of which reveal a very exact knowledge of the structure of placers, remarkable in a race so primitive and backward. This classification from above downward is as follows:

Payason.—Clay, more or less dark, which lies immediately below the vegetation.

Acaron.—Red clay, very sticky, with small pebbles, generally slaty and semidecomposed (batóng patay=dead rock, literally).

Dugcálon.—Yellow clay, more sandy, less sticky, with pebbles of quartz and eruptive rocks, some of great size, others smaller of hematite or magnetite (*tonasé*) with the maximum richness of gold.

Dapanás.—The bed rock is marl, limestone, or conglomerate.

However, these divisions are not all present in the placers, since there are spots, as I have indicated above, where the eroding action of the water has removed some of the upper layers, leaving parts of those below, and because of its richness the natives work the ground with profit in spite of the small thickness.

As for the distribution of values in the placers in the same horizon, that is to say, within the zone of richness, *dugcálon*, it is not uniform nor can it be, if one recalls the circumstances attending its formation.

Those places in which particularly rich values were encountered are called by the natives, the *Monteses* as well as the Visayas, *topadas*, a good Spanish word, and this seems to indicate that Spaniards, probably coming from Mexico, may have once worked these placers.

Method employed in the district for the recovery of the gold.—The method is in reality the same as that employed by the natives throughout the Islands for working the placers, and though quite simple it is very similar to that used even to this day in other countries, and reveals a certain knowledge of the rudimentary principles of mechanics which seems to corroborate the hypothesis of former Spanish work.

To summarize, this proceeding has four phases distinct as to order and object: (1) *Investigation* of the deposit by means of *tujubs*, not always necessary, as, for example, when by other indications or by known signs they know beforehand that the placer is rich in the part they expect to work; (2) *preparation* for the work by the construction of a canal, reservoir, and all the other work; (3) *concentration* of the alluvial ground or the exploitation proper of the deposit, by means of the work in the *banlasan*; and (4) *the cleaning up* (*depuración*) of the sands by hand washing with the *bilingan*, finally obtaining the gold free. Each one of these phases represents quite different amounts of work; the first, as I have just indicated, is sometimes dispensed with; the second, undoubtedly, is the most laborious of all; the third, it can almost be said, works of itself; and the fourth, though quite tedious, has to do with small amounts of material and constitutes only a very small fraction of the work.

In Iponan River Valley the following placers are the best known: Pasayanan, Batinan, Dominolog, Pigtao on the Iponan,

and Bitog Calao on Cagayan River. Along Cutman and Bigaan Rivers there are similar placers. The average of several of these deposits would be, according to the figures of Abella, about 3 grams per cubic meter. The following paragraphs are from Eddingfield's notes(217) on the Cansuran district:

Cansuran River.—The Cansuran Mining district is located about 10 kilometers south of Surigao, Mindanao, near the center of the Peninsula of Surigao. The district extends from a little beyond Mounts Canmajat and Binutong northeasterly to the Surigao River, comprising principally the area between Biga and Tungunaan Rivers which flow into the Surigao.

It is said that over thirty years ago an Englishman operated in the district for a short time. About the year 1885 a Spaniard, Ricardo Gonzales, obtained a concession by which he controlled all the water rights of the district. He did no mining himself, but granted water rights to the natives for 25 per cent of the gold produced, with the privilege of buying at a very low figure all of the gold which they obtained. Since that time the natives have worked whenever sufficient water could be obtained for sluicing.

The country between Surigao and the point where the Cansuran Creek enters the Biga is a wide cultivated valley. A road is in use for 4 or 5 kilometers south of Surigao and is at present being extended; beyond this point, a trail, at places difficult for a horse, leads to the gold district. The Surigao River is too shallow in many places to permit the easy passage of large *bancas* beyond the point to which the road has been built.

The country between the Biga and the Tugunaan is very precipitous and hilly. The rivers and streams have cut deep channels through the country leaving steep slopes. The central portion northeast of Longong is comparatively flat, forming a plateau which slopes gradually toward the Surigao River. Southwest and west of Longong, however, prominent hills with steep sides make up the country.

The gold occurs as placer and is unusually coarse for the Philippine Islands; many nuggets have been found weighing over 30 grams each. The great majority of the gold as brought in by the native workmen would not pass a 30-mesh screen and a large amount would be caught on a 10-mesh screen. The grains are for the most part well rounded showing considerable movement, except on Tagbasingan and Canmajat Mountains where crystallized gold, often wire gold, is found which apparently has not been moved far. The workings on Canmajat are said to be in quartz and the gold to be panned from crushed rock taken from a vein which cuts across Canmajat, striking almost north and south. The average gold in the district runs about 790 fine in gold and 200 in silver.

The gold in the southwestern part of the property, that portion which is made up of high hills and ridges, is found in gravel beds from 3 to 10 meters thick. These beds cover the hills and ridges almost uniformly and have the appearance of being deposited by one or more old rivers. They are made up of coarse and fine gravels. Bowlders weighing several tons are common, and bowlders weighing from 10 to 100 kilograms each are very abundant. Most of these, probably 90 per cent, are andesite,

others are schist, diorite, and red felsite. In the northwestern part along the Cansuran River some quartz pebbles were found, but the greatest part of the deposit contained no quartz pebbles of any size. The bed rock consists of shales more or less slaty in character and schists in which are numerous quartz stringers carrying free gold.

The Surigao Mining Company did some sluicing in this locality in 1911, and later, in 1914 and 1915, the Cansuran Placer Company began large-scale hydraulic operations with monitors, but the enterprise did not prove successful owing, it is said, to difficulties in handling the large bowlders and trees which had to be removed in order to reach the pay dirt.

Several engineers have made tests and estimates of the value of the gravels and dirt in the Cansuran region, the most conservative being that made by an engineer from the division of mines, Bureau of Science, whose average figure was 21 centavos (about 10 cents United States currency) per cubic meter (a little more than 1 cubic yard). Nothing has been done on this property since 1916.

Lianga.—Very little information is available at this writing with reference to the placer deposits on Hinatuan River near Lianga, east coast of Mindanao. Mr. Kane, perhaps the most experienced dredge master in the Philippines, a New Zealander, for many years identified with the industry in the Paracale district, Luzon, has tested it and is now (July, 1922), operating a modern dredge on the ground. Owing to difficulties of navigation on the east coast the dredge was taken overland from Agusan River in sections.*

Binabay River, Mindoro.—From time to time prospectors go to Mindoro, particularly to the Binabay River district (northern part) and sluice the gravels of that stream, but they always meet with difficulties, the chief of which are climate and health conditions. In 1916 flumes for bringing in water for sluicing were built, but no appreciable amount of gold has ever been reported.

Placer, Surigao.—Much has been written about this region, especially by Goodman and by Eddingfield, but the following summary by Pratt in 1914 gives the most important point in its history: its chief interest at present is historical, as very little of consequence is going on there.

* The results of the first clean-up of this dredge have just reached Manila from this out of the way corner of the Philippine Islands and they are rather gratifying, though they indicate nothing remarkable in the value of the ground.

Surigao Province has been a producer of gold for many years, but promises now to become more important in this respect through the operations of the recently organized Cansuran Placer Company. Attention has recently also been directed to Surigao's mineral resources by reason of the discovery by Mr. H. F. Cameron, engineer for the Department of Mindanao and Sulu, that a large area along the eastern coast of the province is covered with iron ore.

Gold mining in Surigao began in very remote times. The metal, detected first in the sands of the rivers and beaches, was traced almost at once to its original home in small quartz stringers and pockets in the andesite, which constitutes a large part of the land mass of the region. Although small, these quartz bodies appear to have been rich in gold at the surface, and at many places the ore has been taken out from open trenches and shallow holes over considerable distances.

One of the best known of the early prospectors in the Surigao gold region was a Frenchman referred to by the Filipinos as Don Maximillano. Apparently this man explored most of the known gold localities in Surigao early in the last century. He is said to have died at Surigao sixty-two years ago. It is stated that he worked first with the placer gold in the vicinity of the present holdings of the Cansuran Placer Company about 11 kilometers south of the town of Surigao. Later he prospected the gold-bearing quartz at Tinabingan, Placer, but ultimately he moved to the eastern margin of Lake Mainit, where he made his home and did most of his mining.

There is to-day little evidence of mining on the site of Don Maximillano's property at Mainit. Bricks are found in one locality at the edge of the foothills surrounding the lake, which the older residents believe to have been part of a furnace used by the Frencham. Depressions which probably mark former shallow pits are found in the same neighborhood. A little gold is obtained by panning in an adjacent gully, and assays of a few pieces of ore encountered near one of the gold pits show fairly high gold values. There is no showing of ore in place, however, and it appears improbable that much mining was done here. The Frenchman is believed by the local people to have been rich, but he might easily have made enough from agriculture in this fertile region and from the sawmill, which he operated in clearing his land, to impress his simple neighbors.

A former mine which is famous in Surigao Province was located on a small island named Campiña, east of the Island of Masapelid in the jurisdiction of Placer. Gold was discovered on Campiña, the area of which is less than 1 hectare, about the year 1883, and mining was carried on assiduously for a period of two years, according to the president of the town of Placer. Mr. Maurice Goodman, a mining engineer, formerly in the Bureau of Science, visited Campiña and found rather extensive old workings, but although he took numerous samples, his assays showed only very low values in gold. It is probable that the miners followed the usual rich stringers in andesite and exhausted the small deposit. It is estimated by some of the old miners that Campiña yielded 30,000 pesos in gold.

Curuon, Mindanao.—Captain Leonard, a veteran of the Philippine military campaigns, has been working some placers by

sluicing on the headwaters of Curuon River, about 75 kilometers northeast of Zamboanga, Mindanao, for some years on a small scale and with only moderate success. There is no question that gold is there, but it is not known that it exists in quantities sufficient to justify any large expenditure of capital. The gold is derived from auriferous schists in the backbone of the peninsula.

The following are the principal difficulties encountered in this branch of mining in the Philippines: "Spotty" nature of the ground, excessively large bowlders and vegetation to be handled, not enough water at one time and too much at another, typhoons, and high cost of installing the proper machinery and of skilled superintendence.

MISCELLANEOUS DISTRICTS

There are numerous localities where both lode and placer gold have been found in small quantities and where larger gold production might be looked for, but they cannot be handled under present conditions. These localities have all been referred to in various issues of Mineral Resources of the Philippine Islands.

Some of the more promising areas for prospecting, in my estimation, are the following: The mineral belt from Baguio north to the Pacific Ocean, lying a little to the east of Baguio and Bontoc and following very nearly the crest of the Cordillera Central (this belt is 10 to 15 kilometers wide and is largely due to granitic intrusions); the cordillera of Camarines Norte south of Paracale; the main cordillera of Panay on the boundary of Antique Province; the eastern cordillera of Mindanao (Diuata Mountains).

It is more than likely that some good gold prospects may yet be located in Palawan, Mindoro, the Zamboanga Peninsula, and the eastern cordillera of Luzon, but I am not so sanguine about these regions as I am of those mentioned in previous pages.

The conditions affecting the welfare of this branch of mining in the Philippines are very much the same as those which have been discussed in connection with the industry in general. The most important needs at present seem to be capital, cheap power, more widespread interest, and a better price for gold; that is, lower cost of supplies, etc.

Production.—Figures showing the gold production for 1920 are given in Table 25, page 352.

IRON

There were nearly 20,000 metric tons of iron ore mined in 1919. The production for 1920 fell considerably below this, amounting to only 116 tons. The reason for the decreased production is that the Calambayanga deposits, which previous to 1920 had been mined by Japanese interests, lay idle. The specific reasons for the cessation of operations have not been learned, but it is to be presumed that the falling market and the wharfage tax (which is virtually an export tax) of 2 pesos per ton made the mining of this ore prohibitive. At the present time the only production is in the Angat district, Bulacan Province, where 83 metric tons of pig iron were made during 1920 from the high-grade hematite of that region. The production is entirely in the hands of Filipinos who are using the very crude, but very cheap, methods of the Chinese. The product is of such high grade, owing to the excellence of the ore and the use of charcoal, that plowshares cast from this material are prized above even imported steel plows. Pratt and Dalburg, who made a thorough study of this region in 1912, estimated its probable iron-ore reserve at 1,200,000 tons.

On Dahikan Bay, Surigao Province, Mindanao, there is what appears to be an enormous deposit of lateritic iron ore, which in many ways resembles the Cuban deposits at Nipe Bay. Pratt and Lednicky, who surveyed the Surigao deposits in 1915, estimated the iron-ore reserve in this field to be 500,000,000 tons. This deposit was made a Government reservation by an executive order of the Governor-General in 1915, and it is this which the recently created National Iron Company intends to exploit. If the deposit is worked, the logical place for the smelting operations is Cebu Island, as the only good seam of coking coal known in the Islands is in Cebu, and the rule the world over is that iron goes to coal. Cebu has other advantages to recommend it as a smelting point; namely, it has the largest supply of labor and it is favorably situated, geographically and commercially.

The importance of iron in the present stage of civilization needs no emphasis here. In the Philippines this need has only lately begun to be felt; it came with the quickening and revolutionizing of the industrial life of the Archipelago. Until 1898, when the aspect of things in general changed, agriculture was the chief industry of the Filipinos and it will continue to be; but manufacturing, as the natural outgrowth of a modernized mode of life and of improved agricultural practice, is on the increase.

As is generally known, iron metal does not, except under rare and special circumstances, exist in the natural state in the earth. Practically the only natural metallic iron is in the form of meteorites. As these are relatively few in the Philippines, as elsewhere, it becomes necessary to turn to the compounds of iron for a supply, of which apparently there is great abundance. The important Philippine iron minerals are hematite (Fe_2O_3), magnetite (Fe_3O_4), and limonite ($2\ Fe_2O_3.3\ H_2O$). These three minerals make up the bulk of the iron-ore deposits in the Philippines. They are generally bedded or blanket deposits, though magnetite is found in some fields in the form of veins.

The principal deposits are the Angat deposits, Bulacan Province, and the eastern cordillera, Luzon; the Mambulao deposits, Camarines Norte Province, Luzon; and the Surigao deposits, northeastern Mindanao.

For the geologic discussion of this subject I have drawn freely upon the work of McCaskey, Adams, Pratt, and Dalburg, especially. Elicaño has contributed the metallurgical discussion.

The Angat deposits.—These deposits were first investigated and mapped in 1903 by McCaskey.(430) Dalburg and Pratt say:(180)

> The Bulacan iron-ore region lies in the foothills of the eastern cordillera about 15 kilometers east of the towns of Angat and San Miguel, Bulacan Province. The region has its major extension in a northeast direction. Numerous isolated outcrops are found for a distance of 20 kilometers along this line, over a width of about 2 kilometers, and two small outcrops occur to the east of this general belt.
>
> The ores are found near the contact of the igneous rocks, both holocrystalline deep-seated rocks (granites) and intrusives and extrusives which form the cordillera, with the sedimentaries lying more or less tilted, on its western flank. The strike of the sedimentary formation is roughly parallel to the line of contact with the igneous rocks. The upper beds are tuffs, clays, and sands of Pleistocene to Recent age, while the lower part of the series is made up of the shales, sandstones, and arkoses which Smith assigns to the Miocene and Oligocene. The limestone horizons which have been noted generally in the Tertiary rocks are identified in this series, and at several places there is an apparent association of the ore deposits and the lower limestone (Miocene).
>
> The ores are essentially hematite and magnetite. These minerals occur as intimate mixtures in all proportions from pure magnetite to pure hematite, although hematite is more commonly encountered. The ores are usually fine grained and massive, but the hematite is sometimes "micaceous." The hematite ores are hard and dense, while the magnetite and the typical hematite-magnetite ores are softer. Quartz is prominent in most of the ore; it generally occurs filling interstices between the iron minerals, but considerable vein quartz carrying only minor quantities of crystalline hematite and magnetite is to be observed. Great bowlders and

blocks of iron-stained quartz mark the immediate neighborhood of the ore bodies. The quartz in these bowlders is evidently the product of the replacement of other rocks by silica. The walls of the shallow pits from which the iron ore is mined are in many instances a soft, dark green rock, which consists largely of hornblendic mineral, sometimes fibrous, but usually massive. It is probable that this rock is in some degree analogous to the complex silicates which are characteristic of some of the Scandinavian iron ores and to which the name "skarn" has been applied by the Swedish geologists. The association of the ore with this wall rock is so general that the native miners recognize the latter as *camisa de bacal* (cloak of the iron ore). Pyrite is characteristic of the ores, and occurs in them as aggregates of fresh crystals or massive in veinlets. Chalcopyrite sometimes accompanies the pyrite, and cobalt has been detected in these sulphides.

Analyses show the ores smelted in the native industry to average 60 per cent or more of metallic iron. The ore is hand picked for smelting, however, and since the miners are very clever at judging rich ore the smelting charges represent better than the average ore. Samples made up of spalls from many bowlders on the outcrops indicate that the larger ore bodies carry on an average from 50 to 55 per cent of metallic iron. The typical ore is of Bessemer grade although in some of the ores the phosphorous content is above the usually prescribed limit; sulphur is generally low. In the purer ores the percentage of alumina (from 2 to 6 per cent) is rather high in proportion to the silica (from 3 to 8 per cent). Alumina and silica are the principal slag-forming constituents of the ores.

Camaching.—The iron-ore deposit in the locality called Camaching at the head of Balaong River lies about 20 kilometers north-northeast of Angat. Camaching is the northernmost of the iron-ore properties in the Angat district and is also the most difficultly accessible property. There is displayed at Camaching, however, a tonnage of iron ore greater than that of all the other properties combined.

Magnetite is the principal ore mineral, but is intimately mixed with black massive hematite.

Montamorong.—Montamorong lies about 7 kilometers south-southwest of Camaching. It is nearer the western edge of the cordillera than Camaching, and is, consequently, more accessible. The ore deposit at Montamorong occurs at the eastern edge of the granite area on the contact between the granite and extrusive rocks—flows and tuffs. Numerous dikes of a dark-colored holocrystalline rock made up principally of plagioclase feldspar and pyroxene cut both the granite and the extrusives in the vicinity of the ore body. The ore body has the appearance of a vein with much-altered and not sharply defined walls. A shallow pit which has been opened on the outcrop reveals the presence of a fault parallel to the apparent strike of the vein (north 60° west) with a downthrow of about 1 meter to the northeast. The vein pitches to the northeast at an angle of 45° at the site of the pit, but it is doubtful if the strike and pitch, as noted, are constant. The workable ore in the vein has an estimated thickness of from 1 to 2 meters, and the outcrop can be followed for 50 meters.

The ore is a soft massive hematite with a considerable quantity of magnetite.

Hison.—The original Hison concession, the demarcation for which was performed in 1816, apparently centered around the middle one of three outcrops which occur about 3 kilometers south-southeast of Montamorong.

These outcrops lie along the eastern border of the granite area. Immediately east of the Hison outcrop is a narrow belt of sedimentary rocks, consisting of limestone, shales, clays, and fine-grained clastic rocks. The limestone is most prominent, and persists southward beyond the Santa Lutgarda outcrop. The beds strike north 20° east, and dip eastward at an angle of 60°. As at Montamorong the periphery of the granite is cut by dikes which appear to penetrate the sedimentaries as well. Although detailed relationships cannot be determined, in a general way the Hison ore deposit occurs between a basement of granite and overlying sedimentaries and is associated with the dike rocks.

At Hison and Santa Lutgarda the ore is identical; at the surface, a massive hard black ore consisting of both hematite and magnetite, while in the shallow pits which have been opened the ore encountered becomes softer and consists almost exclusively of magnetite. Smelting charges carry 65 per cent of metallic iron. Gangue minerals are quartz, pyrite, and the minerals of the characteristic green rock which is found in and near the walls. At the Constancia outcrop the ore is similar, but carries less quartz and a larger proportion of the green wall rock, which here is lighter than usual in color and decidedly fibrous. The Constancia ore is principally magnetite with subordinate black hematite. It is soft, and is marked by nests and veinlets of pyrite. Here, as elsewhere, the pyrite is most prominent near the walls of the deposit.

In the bowlders which mark these outcrops, several thousand tons of ore are available. The width of the ore exposed in the outcrops varies from 6 to 15 meters, but it cannot be assumed that the deposit is continuous between outcrops.

Santol.—Two mining claims located by American prospectors cover the base of Mount Santol along Santol Creek about 3 kilometers south-southwest of Hison. No outcrops of ore in place are to be seen, but the claims are strewn with large hematite-magnetite bowlders aggregating undoubtedly several thousand tons of ore.

The inevitable and intimate association of the ores with vein quartz and the character of this association suggest that the ore minerals, hematite and magnetite, were deposited together from solutions presumably of more or less deep-seated origin. Part of the pyrite occupies cracks in the original ore and must, therefore, be secondary, but pyrite and rarely chalcopyrite also occur in intimate mixture with the ore minerals apparently as original constituents of the ore. Much of the ore appears to be a product of replacement; specimens showing the replacement of limestone, fragmental rocks, felsites, and holocrystalline rocks by ore have been noted. The green wall rocks, which have been cited as comparable with the "skarn" of the Norwegian iron-ore deposits, are believed to be an alteration product resulting from the action of the ore-depositing solutions.

The principal ore deposits occur near contacts between sedimentary and older igneous rocks, both deep seated and effusive. The strike of the

contact between the igneous rocks and the sedimentaries, which is in general parallel to the strike of the sedimentary rocks, is also the strike of the larger ore bodies. The possible conclusion from this fact that the ore has resulted from contact phenomena between the two types of rocks is not tenable, however, because the igneous rocks are not intrusive, but constitute a preëxisting basement.

From the foregoing discussion it will appear that a minimum of 1,000,000 tons of iron ore is probably available in this field. This approximation is made in the absence of any direct information as to the persistence of the ore with depth, and is therefore not to be accepted as a reliable estimate. If the deposit is purely superficial, as it may well be, so far as the evidence from exploration is concerned, then the estimate is too large. From the geology of the deposits as presented in this paper, however, it may be argued that the persistence of the ore to a reasonable depth is probable, and if the ores do persist in depth a great deal more than 1,000,000 tons should be in reserve in this field.

Other observers have suggested that the Bulacan iron ores have resulted from the alteration of pyrite and other iron-bearing minerals by surface waters. Such an alteration would be most complete at the surface; therefore, the ore might be expected to become more pyritiferous with depth and to be unfit for use when the unchanged sulphides were reached. A deep-seated origin, such as is suggested in the foregoing discussion, with the pyrite secondary or at most contemporaneous in origin with the ore minerals, would mean more constancy in character with depth and a more or less uniform distribution of pyrite.

It would not be difficult nor expensive to explore the Bulacan iron-ore deposits by core drilling and thus to determine their character and extent beneath the surface.

My own opinion of these deposits of the eastern cordillera is that they are largely of superficial origin, and core drilling must absolutely precede any large-scale operations. I am the person alluded to by Pratt as having a different opinion as to the origin of these deposits, but owing to Pratt's longer study of these, I would not here press my own ideas.

The Lanatin iron deposits.—I have never visited these, but suspect they are a continuation of those just described, as the axis of the folding in the eastern cordillera, if projected, would pass through the three localities Bosoboso, San Isidro, and Santa Inez. Of these Adams(21) says:

In visiting the Lanatin deposits the writer journeyed by the way of Bosoboso, past the deserted settlements of San Jose, San Isidro, and Santa Inez. At Santa Inez there are small bowlders of iron ore in the river, and the remains of the abutments of a suspension bridge are in part constructed of bowlders of iron ore. Bowlders of iron ore, some of which are from 2 to 3 meters in diameter, are encountered about one hour's walk up the river in the bed of the stream. The mountain to the west of the river was evidently the source of these masses. The lower slope of the mountain was ascended along the bed of a stream which empties into the

river just above the bowlders. The country rock exposed by erosion is an andesite containing numerous small specks of pyrite, and in some places bunches of pyrite were found in sheer zones. The larger masses of pyrite were partially altered to hematite. In places there is a small amount of chalcopyrite present and the alteration has given rise to a coating of the blue and green copper carbonates. The copper ores have been prospected lately, but have not been found in encouraging quantities. On the wall of the ravine, a face of rock was seen which showed a considerable amount of iron ore, coating and replacing the country rock. This has somewhat the appearance of a dyke running up the mountain, although there is no proof that it is, since the dense vegetation obscures the formation excepting in the walls and bed of the ravine. Near the top of the hill there is an outcrop of iron ore. The summit of the hill is capped by a heavy bed of limestone such as is frequently met with in the eastern cordillera. In descending, exposures of a metamorphosed fine-grained clastic rock were seen in the bed of the ravine to the south of the one which was followed in ascending. This rock contains specks of pyrite, but no bowlders of hematite were seen. A simple and sufficient explanation of the origin of the iron ore is that it has been derived from the pyrite which is found disseminated in the country rock and occurring as masses in the sheer zones. It is probable that the mineralization is a result of contact phenomena resulting from the intrusion of the andesite in the sedimentary formation.

The amount of iron ore is sufficient to supply a small furnace operating as a local industry, and utilizing charcoal in smelting, but there is at present no exposure of an ore body which would warrant the establishment of a large furnace.

It should be remarked here that the prospectors who examined this locality report another iron deposit somewhat more promising at a distance of a long day's march in the rugged and very little known country to the northeast.

Iron deposits near Santa Inez.—A deposit of iron which has never been worked occurs a short distance to the north of Santa Maria, in the valley of the Santa Maria River which enters the northeast arm of Bay Lake. The position of this deposit is shown on d'Almonte's map of Luzon, and to the south of it there is indicated an outcrop of coal. From inquiry it was learned that neither the coal nor the iron is of sufficient importance to warrant special investigation.

The Camarines deposits.—The Camarines iron deposits are three in number and are in the following localities: Calambayanga Island, a small island on the west side of the entrance to Mambulao Bay, Camarines Norte; on the long narrow neck of mainland on the west side of Mambulao Bay; and near the barrio of Batobalani near the head of Paracale River, a few kilometers southeast of Mambulao.

I have visited all of these deposits recently (1920) and have had opportunity to confirm the surveys made there by Pratt in 1915, and, rather than recast what that author has written, I will include excerpts from his reports made about that time.

Subsequent work makes it appear that not so much ore will be found available here as Pratt thought at that time to be likely. Only the judicious use of the core drill will absolutely prove these deposits. It should be pointed out, in justice to Pratt, however, that he gave no estimate of probable tonnage other than is contained in the statement that "the ore in sight is undoubtedly to be estimated in hundreds of thousands of tons but the total quantity of ore available is undetermined."

Excerpts from Pratt's paper are as follows:

The ore body on Calambayanga Island appears to be irregular in shape, but to conform more or less closely to the strike and dip of the sedimentary beds in which it occurs. It outcrops on the western part of the island and is roughly oval or lens-shaped in plan. Ore of exactly the same character is encountered on the mainland to the south, where exposures are seen at intervals for a distance of at least 2 kilometers (1.2 miles) inland. A small island south-southwest of Calambayanga Island and considerably to the west of a line between it and the outcrops on the mainland is composed wholly of iron ore of the same character. Again, at Bato-balani, 12 kilometers (7.5 miles) southeast of Calambayanga Island and still near the line of contact between the sedimentaries and the older igneous rocks, iron ore similar in character to the Calambayanga ore is found.

At each of these places the outcrops are marked by great blocks of black ore, angular in form and with pitted, irregular surfaces. These blocks have been designated as bowlders by several observers, but the term bowlder conveys a wrong impression, inasmuch as the masses of ore at the outcrops show no evidence of having been transported, but have the appearance of disintegration products in place. They vary in size up to masses of many tons' weight. At the prominent outcrops they occur to the exclusion of all other rocks, but elsewhere they are isolated from each other and are embedded in yellow, residual clay.

Only the Calambayanga ore body has been examined closely by me. The western half of the island is strewn with blocks of ore. The northeastern part is made up of sedimentary rocks, principally sandstones, or fine-grained clastics, shales, and conglomerates. At the northern extremity of the island the beds strike north 20° east and dip 45° to the west, but toward the south, along the east coast, the strike changes gradually until it is north 60° west with the dip to the south. A bed of crystalline limestone outcrops in the sedimentaries halfway along the eastern coast, and some of the other sedimentary beds are calcareous. Minor outcrops of stratified rocks are found on the eastern coast, but here the strike is north 60° west, and tuffs, agglomerates, and fragmental rocks predominate over other types. These volcanic rocks are less indurated than the sedimentaries on the eastern shore of the island, and there is a consequent suggestion that they belong to a separate younger formation.

Extending north-northwest into the mass of the island from the southeastern point is a great outstanding body of quartz, a lode or vein, with a width of possibly 100 meters. This quartz is mineralized and contains numerous veinlets of iron ore. A shallow pit has been sunk in the quartz near the center of the island, and a sample taken from the wall of this

pit showed upon assay a trace of gold. The sedimentary rocks to the east are highly silicified near the contact with the quartz.

The outcrop of the quartz becomes concealed toward the north-northwest by a mantle of clay, but on the northwest shore, approximately at the point where the quartz should reappear, if it continued so far, there is encountered a dike of dark-colored gabbro between agglomeratic tuff and sedimentaries. This dike is vertical and strikes north 60° west. A small vein of quartz carrying unaltered fresh pyrite was observed in it. Under the microscope the dike rock is seen to be holocrystalline and to consist principally of plagioclase feldspar and pyroxene. The feldspar predominates and occurs in large lath-shaped crystals with a parallel arrangement. The pyroxene appears to be much decomposed, and associated with it throughout the section is magnetite in considerable abundance.

Along the western and northern shore line of the island the blocks of iron ore are present in great abundance and lie one upon another with no intervening foreign material. Farther up the slopes, however, and at the summit of the island the blocks are scattered over the surface, embedded in residual clay.

Fanning studied the ore on the mainland; he traced the outcrop of the ore for a total distance of 3 kilometers (including the outcrop on the island?). The width as revealed to him by occasional outcrops in place varied up to 15 meters. Sedimentary rocks are found on the mainland, as on the island, and similarly are indurated, tilted at various angles, and pierced by dikes. Volcanic tuffs, agglomerates, and flows are prominent on the mainland and on the neighboring small islands.

At Bato-balani the iron ore occurs in large blocks scattered over the side of a hill. The ore is magnetite with some hematite and carries also fresh quartz and pyrite.

The iron ore on Calambayanga Island and on the adjacent mainland is almost pure hematite with only traces of magnetite. The hematite is massive or granular, and the ore is moderately soft and very porous, or vesicular. At places over the exposure a small proportion of pyrite in fresh crystals may be detected in the hematite, and likewise quartz is found sparingly in scattered grains or in veinlets. Copper stains were found in the slightly pyritiferous ore at two places, indicating that some chalcopyrite occurs with the pyrite.

The Bato-balani ore contains much more magnetite than the ore on Calambayanga Island; it is also harder and shows more pyrite and quartz, but otherwise the ores are similar.

The observations set forth in this report have led to the conclusion that the ore on Calambayanga Island is related in origin to the quartz vein or lode with which it is associated. Veinlets of ore are found in the quartz, and quartz occurs sparingly in the ore. The processes which produced the body of quartz probably yielded under different local conditions the adjacent body of iron ore. Both types of mineralization probably resulted directly or indirectly from the intrusion of dikes into the sedimentary rocks near the contact with the older igneous base. Apparently there was some replacement of the wall rocks as well as the filling of cavities and fractures. Probably the limestone and the calcareous sediments were most susceptible of replacement in this manner. The dike of gabbro on the north-western shore of the island with its notable

proportion of magnetite may be taken to represent a part of the intrusive rocks. The tuff and agglomerate on the shore of the island and on the neighboring islands and mainland are surface extrusions which may be related genetically to the dike rocks.

Rinne concluded that the Bato-balani ore had resulted from contact mineralization, probably at the contact of intrusive diorite and limestone. The Bato-balani and Calambayanga ore deposits prove upon examination to be very much alike except that magnetite is the predominant ore mineral at Bato-balani, whereas hematite predominates at Calambayanga. Probably the two deposits are related in origin, and certainly the observations recorded herewith on the Calambayanga deposit are evidence of a genesis similar to that suggested by Rinne for the ore at Bato-balani.

Certain general characteristics are common to the iron ore at Calambayanga, at Bato-balani, and in Bulacan Province: for example, the association of the ore with intrusive rocks in sedimentaries, especially limestones; the nature of the ore minerals; and the presence of quartz in the ore. In some of the Bulacan deposits the replacement of limestone by ore is clearly evident.

The Surigao deposits.—These deposits were discovered by H. F. Cameron, former district engineer in the Bureau of Public Works, Philippine Government, about 1912. They are situated near Dahikan Bay in the extreme northeast corner of Surigao Province, Mindanao Island. He was struck by the similarity to the Nipe Bay deposits of Cuba with which he was familiar. Samples analyzed by the Bureau of Science, which he had collected, confirmed his opinions about the value of the deposits, and, following his official report, the deposit was reserved by executive order pending a detailed examination. In the early part of 1915 Pratt(504) and Lednicky made a fairly detailed examination of the deposit; excerpts from their report will be found in the chapter on Regional Geology devoted to Mindanao and Sulu.

It is extremely probable that other, similar lateritic deposits will be found in the Philippines as in other parts of Malaysia. Only recently word has come that a large deposit, much like the Philippine, has been discovered in Celebes, just to the south of the Archipelago, and investigations by Dutch engineers with the view to its exploitation are under way.

In many other parts of the Philippine Islands there are considerable accumulations of magnetic sands which have been washed out of the igneous rocks, principally andesite and basalt, and subsequently concentrated on the beaches. In some places these deposits are so extensive as to lead one to consider them as possible sources of iron. In fact, some persons have made serious attempts to briquet and smelt the sands from the

beaches of Manila Bay, in Bataan Province, but without success. In Cebu and other islands some specimens of specular hematite have been found, indicating possibilities to be investigated.

IRON SMELTING IN THE PHILIPPINES *

Dalburg(180) and Pratt have the following to say regarding the primitive method of iron smelting used in the Philippines:

> Iron smelting in the Philippines between the years 1784 and 1797 appears from the scant description on the record to have accomplished first a reduction of the iron into balls (bolas) or pasty masses which must have been somewhat malleable since bolos and other implements were made from them. The first smelting was undoubtedly done under the guidance of Spaniards, and can scarcely be spoken of as a Filipino process.

The present-day process and practice have been described accurately and in detail by McCaskey and by Dalburg and Pratt, and have not changed materially within the last fifty or sixty years. An abstract is given in the following paragraphs.

The furnaces are cylindrical stacks from 2 to 2.5 meters in height and about 1.5 meters in exterior diameter. The upper part of the stack to a depth of 1.75 meters is hollow and constitutes the smelting crucible, which is shaped like an inverted truncated cone, circular at the top of the furnace, with a diameter of about 1 meter, and elliptical at the bottom or truncated section of the cone with about 0.5 and 0.2 meter as major and minor axes, respectively. A rectangular runner about 12 centimeters deep and 13 centimeters wide pierces the bottom of the crucible from front to back of the furnace. The back end of the runner admits a single tubular clay tuyèré, which is connected to the blowing apparatus and through which the blast enters the furnace. The front end of the runner, which is placed a little lower than the rear, serves as a tap hole for both iron and slag. A block of quartz-sandstone, locally called *batong-buga,* is set in the wall of the crucible over the tap hole just where the blast, entering through the tuyèré from the opposite side, will impinge upon it. The walls of the furnace are soft-burned brick made of clay and set in a mortar of the same clay, which is the residual resulting from the decomposition of

* This section on Iron Smelting is contributed by Victoriano Elicaño.

the granite found in the region. The sides of the crucible and runner are lined with a mixture of clay and charcoal powder.

The blowing apparatus (*joncoy*) is a hollow log 35 centimeters in interior diameter and 3.5 meters long; it is fitted with a wooden piston which is edged with soft chicken feathers to prevent leakage of air around it. The piston rod is long enough to permit a full stroke when worked back and forth by hand. The blower is double acting, wooden tubes conducting the blast from valves at both ends of the displacement chamber to the tuyèré. In operation the blower lies almost horizontal, one end being raised slightly from the floor to facilitate the work of the operator.

The molds (*hormas*) are made of clay reënforced by rattan or wire. Each mold consists of a base, which is fixed rigidly to a frame or rack, and a removable cover, which is made securely fast to the base by a stick placed across the top of the molds with both ends tied to the rack. For convenience in pouring one end of the rack is raised so that the molds are inclined at an angle of about forty degrees.

The fuel used in smelting is charcoal, usually burned near the smelting plant. A charcoal kiln or an *inglesa* is a rectangular inclosure, the walls of which are made of bamboo poles; it is about 14 meters long, 4.5 meters wide and 4.5 meters high. The logs for charcoal are cut into lengths 1 meter shorter than the width of the kiln, and are corded up inside the kiln, leaving 0.5 meter space between the pile and the bamboo walls. Openings which run longitudinally along the floor of the kiln and up one end of the pile are provided for maintaining a draft. The space around the pile inside the walls is filled with fine charcoal waste and a cover of the same material is spread over the top. The fire is started at the lower end and gradually burns through the kiln, being retarded by the smothering effect of the charcoal cover. It requires anywhere from fifteen to thirty days to burn a kiln of 140 cubic meters of charcoal. The charcoal is obtained in unusually large pieces and is hard and strong, containing about 81 per cent fixed carbon and about 3 per cent ash.

To blow in a furnace, a slow fire is started in the crucible and allowed to burn for several hours, then charcoal is added until the crucible is filled and a light blast is applied. About twenty-four hours after the fire is kindled the blast is increased and a small quantity of ore together with more charcoal is charged at the top of the furnace. Increasingly larger charges are added at intervals until the operation is normal and the furnace is in

full blast. Afterwards ore and charcoal are charged together at intervals of from one to five hours depending on the rate at which the iron comes down. The average charge consists of 43 kilograms of charcoal and 25 kilograms of ore. The ore is broken into pieces with a maximum diameter of about 2 centimeters. When the furnace is working normally, iron is tapped off every three or four hours.

As no flux is added to the charges, the clay lining of the crucible is quickly attacked and eaten away by the charcoal ash, so the smelting continues only as long as the furnace works well or until no more iron can be brought down, ordinarily for a period of from twelve to fifteen days. When siliceous ores are smelted the life of a furnace reaches to more than twenty-five days. The average capacity of furnaces is from 200 to 400 kilograms of metallic iron per day, all of which is made into plowpoints and plowshares. The castings produced are uniformly a white fine-grained iron, which is low in silicon, extraordinarily hard, and contains very little graphitic carbon. This should be expected with a furnace of such a short smelting column and with such a blowing equipment, capable of producing only a comparatively low temperature.

With the shortage of gray scrap and pig iron during the World War, greatly needed in local foundries, attention was directed to the possibility of producing gray iron from Philippine ores without entailing the expenditure of large capital. Improvement of the native practice was naturally suggested as a possible solution. After eliminating countless difficulties in the transaction, the Bureau of Science obtained the consent of Mr. Matias Fernando, a mine and smelting-plant owner of Angat, to carry out some experiments in his furnaces. The experiments were started by T. Dar Juan, F. Reyes, and myself with the introduction of a mechanical blower, which readily demonstrated its advantage over the hand blower by a slight increase of temperature in the hearth, an increase of output, and a decrease of fuel consumption. Further changes, however, were needed and it was planned to introduce some means of preheating the blast and some changes in the furnace design, but funds were not available to carry out the experiments to a successful termination.

Mr. M. E. Heacock has organized the Manila Iron and Steel Company and erected in Bataan a small blast furnace with practically modern equipment. This place was selected because of the extensive fuel supply available from the Bataan forest.

On account of high cost of transportation during its organization, the company planned to utilize in the meantime the magnetite sand which is found naturally concentrated along Limay and Mariveles beach bordering Manila Bay. It is to be regretted, however, that the postwar crisis paralyzed the activities of this company, a consequence to be expected in organizations of this nature starting with very limited capital.

The National Iron Company was created by the Government to establish an iron and steel industry in the Philippines. Mr. A. S. Argüelles, chemist of the Bureau of Science, was able to secure from reputable metallurgists and metallurgical concerns in the United States valuable comments on many important points to be considered in the organization and establishment of an iron and steel industry in the Philippines: Up to this time, however, nothing is known of the probability of materialization of the project.

Although during the last twenty years the agricultural and manufacturing industries in the Philippines have increased considerably, mining has advanced very slowly. With the progress of the above industries the demand for iron and steel products has shown a material increase, amounting to several millions of pesos annually. There exist in the Islands proved commercial deposits of iron ores, which could and should be developed and exploited to counterbalance the great wealth going out of the country annually.

The exploitation of the iron deposits could be effected either by exporting the ores to a neighboring metallurgical plant, or by establishing a smelter in the Islands. Japan and China may be considered as possible principal markets for Philippine ores, with New Zealand and Australia coming next. The problem of metallic iron production in the Philippines might be solved in two ways: blast furnace and electric smelting. The first requires a considerable supply of suitable fuel that can be produced at a very reasonable price; the second, though requiring only about one-third as much fuel, needs a great supply of cheap electric energy.

CHEMICAL AND PHYSICAL CHARACTERISTICS OF PHILIPPINE ORES

The question might arise as to the suitability of the Philippine ores for smelting. In Table 40 are given the analyses of samples taken from the important Philippine deposits. For the sake of comparison. analyses of some foreign ores are also given.

TABLE 40.—*Analyses of Philippine iron ore.*

Constituent.	Bulacan ore.	Calambayanga ore.	Surigao ore.	Mayari ore, Cuba.	Magnetite from Hongkong.	Hematite, Mesabi Range, Minnesota.
Hygroscopic water	0.25		13.50			12.27
Combined water			6.60	11.15		
Silica (SiO_2)	5 02	1.02	1.04	2 26	1.20	6.80
Alumina (Al_2O_3)	4.80	1.31	10.56	14.90		2.23
Ferric oxide (Fe_2O_3)	66 41	97.35	66.80	68.75	70.32	
Ferrous oxide (FeO)	20.64		0.36	0.77	22.53	
Lime (CaO)	0.35				0.60	0.32
Magnesia (MgO)	0.74				3.64	0.22
Manganese oxide (MnO)	0.24	0.11			1.48	
Chromium oxide (Cr_2O_3)			1.15	1.89		
Titanium oxide (TiO_2)	0.23					
Nickel oxide (NiO)			None.	0.74		
Phosphorus (P)	0.052	0.001	Trace.		0.004	0.062
Sulphur (S)	0 02		Trace.		0.11	0.07
Total iron (Fe)	62.54	64.14	54.29	48.65	66.75	58.83

The foregoing analyses show that the average iron contents of Philippine ores are well within the average smelting requirement. The ores from Bulacan and Calambayanga are much richer than those from Surigao, but the accessibility of the latter and the possibly lower mining cost are important points worthy of consideration. With the exception of a few samples, all are within the Bessemer limit as to phosphorus. Sulphur is variable, being high in some and low in other samples, but this element can be controlled by the furnace man.

It is important to note that alumina is high in proportion to silica, as compared with the iron ores most widely smelted elsewhere. This fact will perhaps require the production of high alumina slags, and will necessitate, besides the requisite amount of limestone, the increase of the silica in the ore by the addition of barren quartz.

In usual practice ores high in alumina are generally avoided due to the obscure rôle of alumina in the slags, but J. E. Johnson, jr.,* reports the successful experimental operation of a blast furnace, with perfectly satisfactory desulphurization, in which the alumina in the slag had been as high as 39.5 per cent, with silica as low as 21 per cent on individual flushes and averaging for an entire day SiO_2, 24.7 per cent; Al_2O_3, 36.0 per cent; neutral substances (CaS, MnO, FeO, etc.), approximately 3.5

* Bull. Trans. Am. Inst. Min. Eng. 44 (1912) 128.

per cent; and CaO, the remainder. Weld * also states that, in connection with the high alumina and chromium content of the Mayari ores of Cuba, exhaustive studies and experiments on these ores have been carried out by the Pennsylvania Steel Company, and that it has been announced that all the difficulties have been solved, and steel rails of more than usual excellence, due doubtless to the nickel content, manufactured from them. It might, therefore, be conclusively stated that the special high alumina characteristic of Philippine iron ores does not exclude them from being smelted successfully. It may be superfluous to state that the character of the Surigao ores, except for the absence of nickel, is similar to that of the Mayari ores.

Titanium is present in some of the Bulacan ores but in quantities that would not affect the operation of a blast furnace or the grade of the iron produced.

The ores of Bulacan Province consist of magnetite and hematite in intimate mixture, but of varying proportion. Both minerals are usually massive, although some specular hematite is sometimes encountered. The Calambayanga ore is almost pure hematite with only traces of magnetite. The hematite is massive or granular, and the ore is moderately soft and very porous or vesicular. Therefore, from the peculiarities above described, the formation of fines in more or less considerable quantity might be expected, and these must receive preliminary treatment before being charged into a furnace. There are several processes † of agglomerating ore fines, already known, involving the use or non-use of heat. It remains only for the operator to adopt the one that is most suitable and most economical in conjunction with the smelting-plant equipment.

The Surigao ore offers an entirely different problem. It is principally ferruginous clay, but contains also an abundance of small, round pellets of hydrous iron oxides, as well as fragments or crusts of the parent rock, much altered, porous, and iron stained, but which maintain their original form. The ore is soft and very spongy, or mealy. In utilizing this ore, sintering or nodulizing is necessary, and some means of separating the intermixed fragments of country or other barren rocks will have to be provided.

* Bull. Trans. Am. Inst. Min. Eng. 40 (1909) 312.

† Johnson, jr., J. E., Principles, Operation and Products of the Blast Furnace, 1st ed. (1918) 193.

MINING COSTS

The present exploitation of the Bulacan deposits does not develop them at all; nor has the work done on the Calambayanga revealed much as to the character of the deposit, which cannot be accurately determined owing to obscure geologic relations. It is, therefore, dangerous to advance at present any tentative estimate on the mining cost until more exploratory and development work has been done. Pratt and Dalburg noted that the walls of the ore bodies in Bulacan Province are invariably soft; similar conditions are found in Calambayanga. Such conditions require a great deal of underground timbering, a very expensive item to add to mining costs in the Philippines. The Surigao deposit has been more or less thoroughly studied, and its mode of occurrence makes its mining less problematic than that of the former two; an estimate of the cost could be fairly calculated after it has been decided what kind of excavating and transportation equipment shall be used.

Unless a smelter is built near the mines, the transportation of the ores from the mines to a place from which shipping can be made either to local or to foreign smelters is a problem that must be solved by the prospective operator.

The Bulacan deposits are isolated in a mountainous region, 50 kilometers or more from a railroad line. The Surigao and Calambayanga deposits are near to points that can be developed into good harbors, but the sharp relief offered by the regions will require considerable expenditure, especially as they are subject to the sudden formation of large streams during the rainy season. Aërial cable transportation will probably be the most convenient.

Labor is scarce in all three districts, as most of the people are engaged in agriculture and cannot be depended upon for continuous work in the mines. The timber supply in the districts is not abundant, either for fuel or for construction.

FUEL SUPPLY

Deposits of coking coal suitable for blast-furnace use are found in Cebu and in Sibuguey, Mindanao. Exploitation has been started in these fields, but only on a small scale. Development of the coking seams is not very extensive and the probably available quantity is still unknown. It will take several years to place either one of the districts on a producing basis capable of supplying continuously a blast-furnace plant.

For a charcoal supply the extensive forests of Zambales, Bataan, Tayabas, Mindoro, Negros, and Mindanao might be pointed out. It will, however, be necessary to keep up the reforestation of the area selected, in order to insure future supply. To this end the use of ipil-ipil (*Leucaena glauca* Benth.) may be suggested, the wood from which makes a strong and hard charcoal.

Semianthracite is also being mined at Sibuguey, but like the other fields is still inadequately developed. This may be counted upon as a possible source of fuel supply for blast-furnace smelting.

FLUX SUPPLY

On account of the low silica content of Philippine iron ores, silica flux might be needed besides limestone. A good supply of both limestone and silica can be found near some of the ore deposits, all of which could be transported together with the ore. There exists, besides, a good supply of limestone and siliceous tuff near the coal mines of Cebu.

POWER SUPPLY

Power can be either steam or hydro-electric. For the use of the former the locations of fuel supply have already been mentioned; for hydro-electric development the following are possibilities: Agus River draining the inexhaustible reservoir of Lake Lanao, in Mindanao; Angat River in Bulacan Province; and Agno River in Pangasinan Province. A report on the power possibilities of Agus River has been submitted by Chas. Bradshaw, formerly of the Bureau of Public Works, and is in the files of that bureau. Seven possible power sites are mentioned, with heads varying from 160 to 400 feet, and the total available power is about 300,000 electric horse power, at a cost, estimated on prewar conditions, of from 40 to 90 pesos per electric horse power installed. General C. de las Heras, in a paper read before the Manila Merchants' Association in May, 1912, described several ways of developing hydraulic power in Angat River, and he estimated that 11,400 electric horse power could be developed at a cost of about 4,500,000 pesos. The Bureau of Public Works has at present under study the possibility of developing Agno River, which is said to be capable of furnishing 1,000,000 horse power.

SMELTING PROCESS

It has been mentioned before that either blast furnace or electric smelting could be adopted for the production of metallic iron. Granting that there is an abundance of good iron ore and fuel and a possibility of developing cheap hydro-electric

energy, the commercial success of either process will depend on the possibility of continuous operation. It has been pointed out that Japan, China, New Zealand, and Australia are possible markets for Philippine ores; the same may be said in connection with marketing the pig and other iron products. The advisability, however, of counting upon these countries indefinitely as markets for Philippine iron is not commercially sound, because all of them have already started in the iron industry themselves, and Japan and China have, each and together, extensive programs for developing the iron deposits on the Asiatic Continent. To be conservative, therefore, it would be advisable to depend only upon home consumption in the estimation of smelting-plant capacities.

The total imports of iron and steel and their various manufactures amounted to 37,575,421 pesos in 1920, 38,621,929 pesos in 1919, 22,464,508 pesos in 1918, and 10,023,155 pesos in 1917.

TABLE 41.—*Showing the most important iron and steel products imported into the Philippine Islands during 1920 and their quantities and values.*

Article.	Quantity.	Value.
	Kilos.	*Pesos*
Pig iron	2,149,201	170,385
Bar iron	524,320	107,549
Bars or rods of steel	14,486,984	2,842,005
Railroad materials	22,451,041	3,196,580
Corrugated roofing	4,324,336	1,741,230
All other sheets and plates	3,470,774	984,748
Structural iron and steel	7,138,851	1,711,891
Wires and cables	2,578,901	1,133,125
Nails, spikes, and tacks	2,402,863	682,071
Needles, nuts, bolts, washers, rivets, screws, and tools		3,239,926
Pipes and fittings	4,387,395	1,602,384
Total	63,914,666	17,411,894

It will be noticed that the local demand for pig iron is very small, and any project for establishing a smelting plant will have to be developed along the lines of greater demand. Were the capacity of a plant based on the total iron imported, it would require a daily output of about 200 metric tons of iron, operating 350 days in a year. The operating cost of a blast furnace of this capacity is not very economical, being comparatively higher than a furnace of two- or three-fold capacity.* With a more conservative figure, say 100 metric tons or less

* Johnson, op. cit. 513 and 514.

per day, the disadvantage of a blast-furnace plant will become more apparent.

The increasing use of electric furnaces for production of steel of different kinds, and the adaptability of such furnaces to electric ore smelting make their use more convenient and perhaps more economical than the operation of blast furnaces, especially when a very small daily capacity is to be considered. Of course, the development of hydro-electric power will entail considerable initial capital; yet, bearing in mind the amount of capital to be invested to develop and to keep up the exploitation of a fuel supply in order to insure continuous operation of a blast furnace, the advantages will still be in favor of the electric furnace; primarily, because the amount of capital to be invested in the development of a hydro-electric plant can be fixed, or closely estimated, while the capital needed in the exploitation of coal will vary greatly according to conditions that can only be determined after considerable development work; second, because the price of electric energy can be calculated from the start, while the mining costs of coal will depend on labor and underground conditions, which are very variable factors; and, third, because the extent of the Philippine coking coal supply is not yet definitely known, while the hydraulic power resources have already been studied. Another point worthy of consideration is the fact that, if Agno River is developed, not only the iron industry will be benefited but also the gold mining of Benguet, the manufacturing industries of Manila and, incidentally, the agriculture of the intervening provinces.

MANGANESE

Manganese occurs as psilomelane, pyrolusite, and wad in Ilocos Norte, Pangasinan, Bulacan, Tarlac, and Masbate Provinces. Manganiferous ores are found at other places in intimate association with gold-bearing calcite and quartz veins. No production is reported to date, although some of the deposits warrant exploration.

LEAD AND ZINC

Lead and zinc minerals have been found in many parts of the Philippines, always associated. There are only two deposits of any note, but at present there is no mining of the minerals. The most-promising deposits seem to be those on Marinduque Island, which Goodman(293) visited in 1907. He did not at that time find any lead deposits of particular value, but develop-

ment has continued interrupted since that time. Mr. E. E. Calvin has furnished the following notes relative to the deposits of his company, the Marinduque Mining Company:

The fifteen claims in this group were located during the year 1916. They are located on the east side of Marinduque Island, about halfway between Santa Cruz and Torrejos and are about 3 kilometers from Salamaga Bay. Development work has been done to the extent of 20,000 pesos in the past two years.

The veins are true fissure veins, and are from 4 to 10 feet wide, carrying lead and zinc in about equal proportion, an average of 6 per cent lead and 6 per cent zinc. Rich ores are found in many places, some running as high as 60 per cent lead and others as high as 45 per cent zinc. Some of the veins carry 2 to 3 per cent copper.

The ores are galena and sphalerite embedded in quartz; the country rock is andesite. The main veins cross four rivers, and the ores are found in solid formation in river beds; good backs, in some cases 500 feet, are to be had between the rivers.

Testing was done in 1918, a 12 per cent lead and zinc ore was jigged in a 20-inch by 20-inch single hand jig and a 60 per cent lead concentrate and a 45 per cent zinc concentrate were obtained. The ore was crushed by a 500-pound dolly bar spring pole lift.

The concentrates with some picked ore were smelted in an open-hearth furnace; a small amount of pig was obtained. The lead concentrates carried 6 to 8 per cent zinc, which made smelting very difficult. With a modern concentrating plant, cleaner concentrates can be obtained, which can be easily smelted in the open-hearth furnace. Charcoal made at the mine was used.

Plenty of water can be had at mill site for milling purposes, but not for power. Mining timbers and firewood are plentiful near the mine.

At Mount Acsubing, Cebu Island, attempts to mine galena were made in Spanish times, but without much success. At this place, which I have examined, the galena occurs as stockwork stringers in andesite, near the contact between this formation and the overlying limestone (Pliocene?). The galena from this place showed a high content of silver.

Some galena has been found in many other localities, but today only one deposit is receiving any attention; namely, the one that Mr. Paul Schwab is developing near Milagros, Masbate. He is preparing to erect a lead furnace on his property.

MOLYBDENITE

Molybdenite was first reported from the Philippines by me in 1905. Very small amounts in flakes were found in some quartz veins, associated with other veins carrying copper sulphides, in the Loboo Mountains of Batangas Province, Luzon. This mineral has been noted in one or two other localities, Baguio district for one, but there is no production.

PLATINUM

This precious metal has been found in very small flakes in placer borings in the Mariquina River basin and at other points just north in Luzon. Recently concentrates from the Lianga dredge, Mindanao, have shown considerable platinum content, though not sufficient to cause excitement. Basic igneous rocks related to those from which platinum is derived by erosion are known to exist in northeastern Mindanao.

SILVER

Until recently, silver unalloyed with gold was not known to have been found anywhere in the Philippines, but from the Acupan camp in the Baguio district native silver has recently been reported. However, most of the silver produced in the Philippines occurs alloyed with gold. Some ores carry as much as 5 ounces of silver to 1 of gold. There is also an appreciable amount of silver in the lead ores of Marinduque and Cebu, but those deposits are not being worked.

WOLFRAMITE

Specimens of wolframite have been brought in from time to time and exhibited in the Philippine Expositions in Manila. The specimens were always small, and purported to have come from Antique Province, Panay. Though the specimens are clearly genuine, I have no other knowledge of the occurrence of this mineral.

HISTORY OF MINING IN THE PHILIPPINE ISLANDS

The history of mining in the Philippines, until within the last few years, has been in the main a long record of failures, and at the present time there are only perhaps a half dozen mines that are earning sufficient profits to make the ventures worth while. One of these is the Philippine Dredges Company, an Australian and New Zealand company, with a fleet of four dredges on Paracale River, only one of which is active. Other successful mines and mining companies are the Syndicate and the Colorado, two quartz properties on Masbate; the Benguet Consolidated Mining Company, near Baguio; the Philippine Coal Mining Company, on Batan Island; and the group of crude iron furnaces owned and operated by Filipinos in Bulacan Province, Luzon. The Benguet Consolidated is the most successful of these. Mining in the Philippines has been more successful since 1898 than in all the centuries preceding.

GOLD

Probably the earliest operations* in these Islands, as elsewhere, were on placers; the work consisted of more or less

* Of the many references in early reports, relations, and chronicles referring to this subject the following are cited:

Expedition of Villalobos 1521–69. "One, Alvarado, in 1544 was told 'at Mindanao' that there were three gold provinces—Mindanao, Butuan (which is now known to be in the northeast part of Mindanao) and Bisayas. Butuan has the richest mines of the whole Island." Blair and Robertson 2: 72.

In 1565 Legaspi issued a proclamation regarding gold taken from Indian burial places, exacting a certain proportion as tribute to the crown. Blair and Robertson 2: 172.

Relations of Capt. Juan de la Isla (1576) mentions the mines of "Masbate." "There were found gold Mines two to four estados [1 estado = 2 meters approx.] in depth." Blair and Robertson 3: 195.

The "Mines of Paracale" are mentioned in a letter from Andres de Mirandaola to Felipe II in 1576.

Memorandum to the Council of Spain from the first General Junta of Manila (1586) "For almost the only wealth of these people has been in the mines and metals * * * there are no hereditaments, or cultivated farms or crops," etc. Blair and Roberston 6: 159.

Mining among the Igorots was mentioned by Capt. Alonso Martin Quirante in Relation of 1621–24. Blair and Robertson 20: 276.

haphazard and desultory washing of the sands and gravels in the various streams. There are numerous traditions relating to the early visits of the Chinese to the Islands, who came to seek gold treasure, and the raids of the Moros into the northern provinces where gold was known to exist.

In the Chronicles of the Franciscan Order in the Philippines Father San Antonio refers to the word *mait* as the Chinese name for Mindoro. It seems that *mait* in Chinese stands for "gold." It may also refer to Masbate where there are remains of old Chinese workings near Aroroy. Whether these represent the activities of Chinese before the Spanish Conquest or are of a later period cannot be definitely ascertained; but it is claimed, in support of the theory of ancient workings, that pieces of Chinese pottery older than the Ming Dynasty have been found near the old tunnels and open cuts. There is very little definite information in regard to these remote times and operations, and the details are not essential now. Suffice it to say that gold has been and can be panned from streams from one end of the Archipelago to the other.

I am indebted to Prof. H. Otley Beyer for the following memorandum:

> Some years ago there was found in a tributary of the Agusan River near Esperanza, Mindanao, a massive golden image which for historians, archeologists, and miners is of great interest. The image was of twenty-one carat gold and weighed about 1,790 grams, the color of the gold being very pure yellow. The figure of the statuette 8 to 9 inches was of a Buddhist deity and the style of art was very like that of the Ngandjuk Period in Javanese art.

The image, according to Professor Beyer, clearly was not made in Java since the workmanship is cruder than that of the Javanese and the gold is of a distinctly different color and quality from that employed in such work in Java. Professor Beyer's opinion is that Javanese miners worked the Mindanao gold deposits as early as 1350.

The most talked-of district for the last three centuries, perhaps, is the Paracale-Mambulao district in Camarines Norte. The history of placer mining in the Philippine Islands is in large part the history of this district. The first operations here were those carried on by Filipinos with the *batea*, a wooden pan. Then there came into use a small dipper dredge, with a treadmill device for raising the dipper (Plate 24), capable of handling only 2 or 3 cubic meters per day. The third stage in the development of the industry came with the installation of

three medium-sized but modern dredges on separate properties. Two of these were New Zealand types and one a California model. The fourth stage, which has already been entered, is the consolidation of properties and the utilization of large-capacity dredges, capable of handling from 2,000 to 3,000 cubic yards per day.

In the early days, long before American occupation, Mambulao, which is now a mere collection of shacks, was a city of much importance due to the flourishing gold mining and the fact that the Spanish galleons from Mexico sometimes stopped there. I recently saw some Spanish silver coins dredged up near this town, bearing the date 1739.

Concurrently with the crude attempts at dredging in the days before American occupation over a score of arrastres of the Mexican type were in use in the hills surrounding Paracale and Mambulao. To-day only one of these can be seen, and it is no longer in use.

The year 1894 is an important one in the history of this district. It is known as the "prohibition," when the Spanish Government prohibited the Filipinos from engaging in the mining industry.

At the present time this district, which was again flourishing during the decade from 1905 to 1915, is almost dead. The banner year in this district was 1915 when there were nine dredges, all told, operating in Paracale, Gumaus, and Malaguit Rivers.

In quartz mining the first step was marked by the use of the mortar and pestle, a universal device among primitive people. This was succeeded by the arrastre, which apparatus was introduced by the Spaniards from Mexico into the Mambulao district. Then came the stamp mill, erected by the Philippines Mineral Syndicate, which company came to grief, however, as a result of the insurrection of 1896, before producing anything. With American occupation came the floating of two quartz-mining companies, the Tumbaga and the San Mauricio, which used still more up-to-date machinery. In 1910, however, both of these shut down, and there are practically no operations on quartz lodes worthy of mention in this district at the present time.

The history of operations in Masbate and Benguet has been similar in many respects, but with the difference that those two districts are better adapted to quartz mining. All attempts

at dredging in Masbate have so far proved futile, while the Benguet country never was adapted to this class of mining.

The chief events in the history of Benguet are the erection of Hartwell's 3-stamp mill in 1903; the beginning of operations by the Benguet Consolidated Mining Company in 1907; the typhoon of October, 1909, which severely crippled the plants of the largest two mines; and the beginning of operations on the Headquarters property in June, 1911. In 1914 the Benguet Consolidated plant was rehabilitated, and to-day it is the greatest gold producer in the Philippines.

In Masbate there have been many ups and downs also, but at present there are two successful mines in operation on lodes, the Colorado and the Syndicate.

COAL

Coal in the Philippine Islands was discovered by Europeans, in 1827, on Cebu, and on Batan Island in Albay Province in 1842. The first coal entries were made on Batan Island in 1847, and the first concession on Cebu was given in 1853. Very little mining was done until after 1890. The two most-important properties were the Bilbao and Chifladura mines on Batan, operated by the Minas de Batan Company, and the Compostela and the Camansi mines, consolidated by Enrique Spitt, on Cebu. These failed and have done nothing since the insurrection. A very comprehensive plan for mining operations on the part of the Government with Enrique Abella, chief of the mining bureau, in charge, was about to be consummated when the insurrection broke out in 1896. In 1904 the United States Army began exploring Batan Island, but never accomplished much, and in 1910 operations ceased by order of the Secretary of War. In 1907 the East Batan Coal Company began operations and did fairly well until 1911, when it went into the hands of a receiver and was bid in by the Government to satisfy its preferred indebtedness. With the coming of the World War and the need for coal at any price the Philippine Coal Mining Company began operations near the old site of the East Batan Company mine, and in 1921 this was the largest coal mine in the Islands. In 1918 the National Coal Company was formed. Its career has been a checkered one, but now, at the end of 1922, it has reached the production stage.

IRON

The earliest record contained in the archives of the Bureau of Science with reference to iron mining bears the date

December 12, 1781, and this is an order of instructions to the Governor of Angat, Bulacan, Luzon, through the Governor of Bulacan, from the Superior Government of Manila to render every possible assistance to Chaplain Juan Belli of the Armada in the working of his mine. However, very. little was accomplished in this undertaking owing to "the indolence and repugnance with which the natives assisted in the labor of the works."

The next that we learn in chronological order is that Santiago Hison, past captain of the Guild of Mestizos of Angat, makes a petition to the Governor of Angat asking that he be declared the discoverer of the mine Sapang Bacal. The entire history, dimensions, and production of this mine are not known. After passing from one owner to another, and ownership being contested several times, the mine at last came into the possession of Mrs. Maria Altesa Fernando, one of the most interesting personalities in the mining industry in the Archipelago. Several other "mines" in Bulacan have crude furnaces erected near them, but Mrs. Fernando has perhaps made the greatest success of the business. There are now on her property several crude furnaces which turn out approximately 150 tons of iron a year; the iron is made into plowshares and sold in Bulacan and neighboring provinces.

In 1917 a Japanese company leased the property on Calambayanga Island in Mambulao Bay, Camarines Norte, and until the close of the World War mined and exported ore from that place.

Early in 1920 a furnace was erected at Limay, on Manila Bay, to treat briquetted magnetic sands, but this has not attained success.

Perhaps the most important event in the iron industry in the Philippine Islands was the discovery, about 1912, of a large deposit of lateritic iron ore by Mr. H. F. Cameron, a Government civil engineer, in Surigao, Mindanao. The Government has since reserved this deposit. The National Iron Company was soon after organized to exploit it, but nothing has been done by this company in the field.

COPPER

The Spanish mining engineer Santos,(538) in his report of 1862, says:

> Even in some of the most ancient history of these islands copper is cited among other metals as one of the products which nature affords with considerable abundance, the natives of the mountains utilizing it

for arms, ornaments, and in a profitable business, but the most noteworthy document which claims attention by its official character and in the exactness as later verified, is the communication to the Governor, His Excellency the Captain Sr. Don Pascual Enrile of 1833, in which he states that the utensils that the Igorots of the rugged mountain ranges which separate the province of Cagayan from that of Ilocos, made of the copper from the mines, have been known for several centuries. With this communication were sent numerous spikes of the metal mentioned, which, assayed in the Dirección General de Minas, gave such good values that not only was it recommended that mines be opened for the exploitation of so much mineral, but it gave rise to the creation of the inspection of 1838 and the mining law of 1846.

In 1850 a military expedition was sent to this region (near Mankayan in Lepanto, Mountain Province, Luzon) to make an investigation. Antonio Hernandez, a Government engineer, went with the expedition and made maps, collected specimens, etc. He found that the Igorots had made a number of small pits and shelves, dug out the high-grade ore, and afterward smelted it in a crude way which has been fully outlined in Santos's report. A translation of this report is included in a paper by Eveland.(236) The report of Hernandez awakened considerable interest, and the governor took steps to carry on mining and smelting on an improved basis. However, it was not until 1856 that an exploration for demarcation of the property was made. Finally an agreement was made with the Igorots of that section by which 500 pesos were paid to the Government for the concession. The Igorots were guaranteed employment in the mines, a stock company was formed under the leadership of Mr. Balbas, which laid out two pertenencias of 83,000 square meters each, and preliminary work was begun. The company operating here was called the Cantabro-Filipino Company.

The year 1860 marks the first actual production, and in 1861 about 25 pounds of copper were produced; in 1862, 1,800 tons of ore; and in 1866, about 234,807 pounds. Up to 1874, the total output was about 2,500,000 pounds of copper. In 1875, this company suspended work. The cessation of work was probably due to the death of Santos, which occurred in that year. From that time the mines have remained idle, except for the crude operations of Igorots and Chinese, and the prospecting and development work done by Americans.

All attempts to float the property have been unsuccessful. This is the only part of the Philippines where a commercial deposit of copper has been discovered.

PETROLEUM

The first mention in geologic literature of gas or petroleum in the Philippines, so far as is known, is found in the description of Panay, by Abella, 1890.

In 1896 an oil well was being bored on the estate of Smith Bell & Co. near Toledo on the west coast of Cebu. In that year an insurrection broke out against Spanish rule and the drillers (Americans) were driven from the well, which has remained idle ever since. It is now choked with rubbish.

About 1910 a number of Americans became interested in petroleum seeps, long known to the Filipinos to occur on Bondoc Peninsula in Tayabas Province, Luzon, but apparently unknown to the Spaniards. Two shallow wells were dug near those seeps and some oil was pumped, but nothing of any great importance has been done since then except to keep up assessment work on the properties. However, several foreign petroleum companies have from time to time made surveys of this and other fields.

About the end of 1917 there was considerable excitement over the discovery of oil in the Cotabato region of Mindanao. In 1919 Act 2814 was passed, providing for the creation of the National Petroleum Company, but this company has done no active field work.

In August, 1920, the Philippine Legislature passed an act "to provide for the exploration, location, and lease of lands, containing petroleum and other mineral oils and gas in the Philippine Islands," and rules governing the same were made by the Secretary of Agriculture and Natural Resources. In November, 1920, ground on Bondoc Peninsula, Tayabas Province, Luzon, was leased to the Richmond Petroleum Company, a subsidiary of the Standard Oil Company of California, and in March, 1921, drilling was begun.

HISTORY OF MINING LEGISLATION IN THE PHILIPPINE ISLANDS

Paralleling the history of active mining operations in the Archipelago is the history of mining legislation, which may be divided into four distinct periods.

The period of Spanish legislation.—The period from 1846 to 1896 was not marked by any conspicuous successes and it is more than likely that the type of legislation was largely to blame for this condition. The Spaniard, like other peoples of Latin origin, strongly favors regulations; his mining operations have been so fettered by the red tape of regulations that he often

overlooked the main business in hand. The Royal Decree of 1846 is theoretically a masterpiece, but practically of little use, judging by results. However, this was the great period of discovery, if not of recovery. During the insurrection (1896 to 1900) there was an unproductive interval of several years. Everything was in a state of transition and uncertainty. It was a bad time for such a sensitive business as mining.

The period of American legislation.—With the coming of stable conditions, new blood, and the passage of the Act of Congress of July, 1902, began the Anglo-Saxon period, in both mining and legislation. With few changes, the basic principles of the American mining law were adopted, thus vastly stimulating the industry, and American prospectors, mostly discharged soldiers, swept over the Archipelago, visiting every island. Notwithstanding this invasion, very few deposits of mineral not known before were brought to light during this period, though several mining ventures were started. It was a period of active and successful mining.

The period of Filipino-American legislation.—In this period, beginning in 1913 and continuing to 1921, the principal thing to be noted is the transition from the old freehold basis to the leasehold for coal and petroleum. The acts bringing about this condition were passed by the Philippine Legislature. There is a partial return to the principles underlying the earlier, Spanish codes, the dominant feature of those being the assertion of the Regalian doctrine; that is, that the state and not the individual is the owner of the minerals. This is the period of nationalization and experimentation.

The period of Filipino legislation.—The fourth period has not yet begun, but will be entered upon with the passage of a complete new mining act and the organization of a mining bureau to administer its provisions.

This brief history of mining in the Philippines would be incomplete and inconsiderate were it to contain no reference to the practical mining men who have worked hard and long to wrest the treasures from Nature. I have already mentioned the most conspicuous names of the practical miners and engineers of Spanish times, and shall now devote attention to that band of hardy Americans, New Zealanders, and Australians who have been working well during the two decades and more of American occupation.

It will be impossible to mention all of these men, but without meaning to indulge in invidious comparisons (for all have

contributed some noteworthy share to the work) a few of the most conspicuous must be named.

Among the earliest prospectors in the gold fields were Messrs. A. Heise, Herbert, Edelmeir, and Berkenkotter in Masbate. Either Mr. Heise or Mr. Herbert was the first to locate claims now owned by the Colorado Mining Company, and Mr. Berkenkotter those upon which the Syndicate mill is operating. Mr. Edelmeir has the distinction of being the first American to prospect for lodes on Masbate Island, and I am indebted to him for much information concerning the early history of mining in that region. Indelibly connected with the later history of Masbate, and with the mining industry in general, is the name of Col. H. B. McCoy, one of the most constructively active of the Americans who remained in the Philippines after the Volunteer Army of 1898 was disbanded.

In Benguet we note first the name of Jack Hartwell, who built the first stamp mill in that region. Hartwell died of cholera in Baguio in the early days, and his little 3-stamp mill has long since been dismantled.

In 1902 Mr. H. Clay Clyde, an American prospector, discovered the Benguet Consolidated lode in Antamok Creek, which is the bonanza of the Far East. Mr. Nels Peterson and Mr. M. A. Clarke, with Mr. Clyde, organized this company. Mr. C. M. Eye, mining engineer, and Mr. A. W. Beam, to-day the president of the company, have done perhaps more than any others to develop the property to its present secure place. Mr. O. L. Kettenbach is the present able superintendent.

Another noteworthy prospector of the district is John ("Tex") Reavis, who is to-day one of the best-known men in the mining fraternity in the Philippines.

One name, that of H. Phelps Whitmarsh, a leading business man of Baguio to-day and long a mining promoter, will always be mentioned in connection with this district. Mr. Whitmarsh, who got his first mining experience as a mere boy in Australia, has done perhaps more than anyone else to fight the uphill battles of mining in this region and is now engaged in promoting still larger schemes for developing this field.

In the Paracale field there is a host of names, all deserving of mention. Of these the most conspicuous is that of Judge Frank B. Ingersoll, who has done more than anyone else to promote the interests of this district, and who has been active in connection with the industry in general for nearly twenty years.

In the practical operations Messrs. Kane and Telford, New Zealand dredge masters, are perhaps the best known.

In lode mining in this district Mr. A. C. Cavender and Mr. John Moissan have perhaps been the most active. Mr. John Mueller's name is the one most associated with mining exploration on Marinduque, but that of Mr. E. E. Calvin is almost as well known.

In the Tayabas oil field Mr. E. W. McDaniels has been the longest identified with the slow developments of that region. In conection with the "asphalt" deposits of Leyte Wm. H. Anderson deserves special mention.

In the coal fields many persons have been active, but ex-Governor A. U. Betts, of Albay Province, has the distinction of having been longer connected with the industry than any other, and he has been the most successful. He is the original promoter of the East Batan coal mine and is interested in the present Philippine Coal Mining Company, near the site of the old mine.

One of the most picturesque, if not successful, figures among the old-timers in the Philippines was "Al" Wright, a former color sergeant with the Rough Riders under Roosevelt in Cuba. Wright's Philippine activities were confined largely to the Mankayan-Suyoc district in the highlands of Luzon.

In mentioning exploration work in Mindoro, Panaon, and other less well known localities the name of Mr. Villager is always heard. He is one of the oldest and hardiest of this band of prospectors.

In the early days of American occupation there was a small army of prospectors let loose upon the country, many of whom did yeomen's work in opening up the wilderness. Most of these have gone; some have died, others simply left disheartened, as they were given little or no encouragement, and the country has lost a valuable asset, since there are none to take their places.

Prospecting is peculiarly an American profession, and as yet the Filipino shows little capacity or desire for this sort of hard, active, free life. It has been suggested by a Filipino mining engineer that the reason for this Filipino attitude is, principally, his lack of knowledge concerning mining. The same condition exists in the United States, where people who are engaged in agriculture or other industries show very little or no interest in mining. It takes a man who either has been engaged in mining work most of his life, or has lived in the neighborhood

of an active mining district, to appreciate and enjoy the miner's or prospector's work and to entertain constant hopes for some success. This is illustrated in the Philippines in all the districts where some kind of mining has been done. However, most of the people benefited are illiterate, and are obliged to do what they have seen done, modified only perhaps by their personal experiences, because they are not able to acquire the knowledge requisite for advancement. The many failures of the pioneer Spanish and American activities are perhaps responsible for giving the Filipinos a somewhat distorted idea and distrust of the mining industry.

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The first attempt to compile a comprehensive bibliography of the geology of the Philippines was that of Becker.(50) Nearly ten years later Ferguson prepared a somewhat complete list of geologic papers that had been published up to the year 1910, but his bibliography was never published in its entirety. Consequently, nothing resembling a complete bibliography appears in the literature, with possibly one exception.(579)

The present bibliography, therefore, is based largely upon the work of Ferguson and of Becker, with amplifications and additions. It is as nearly complete as my knowledge of bibliographic work and the library facilities in Manila will permit. It is thought, however, that few important references up to and including the year 1920 (and a part of 1921) have been omitted.†

It has been found advisable to omit unsigned articles. One or two pages of literature on geology, mining, statistics, and related subjects will be found here and there in scientific journals, but those that are unsigned or under such authorship as "Manila," "An occasional correspondent," etc., have not been included. Reviews and abstracts have been noted as far as practicable. In view of the fact that it is desired to furnish as complete a bibliography as possible, I could not discriminate in favor of only the most-scientific articles.

Father M. Saderra Masó, S. J., of the Philippine Weather Bureau, added many references which otherwise would have been omitted. His careful assistance is greatly appreciated. Miss Mary Polk, librarian, and assistants at the Bureau of Science library have rendered valuable aid in the preparation of this work.

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INDEX

Abra River, 117.
Abrasives, 358.
Abstract of Philippine mining laws and regulation, 539.
Acaron placers, 441.
Actaeon sp., 314.
Actinolite, 334.
 schists, 106.
Active and solfataric volcanoes, 291
Acupan mine, 434.
Agate, 344, 384.
Age of Philippine placers, 136
Agglomerates, 68.
Aggradational plains, 54.
Agno beds of Luzon, 112.
 River, 116.
Agriculture on Marinduque, 149
Agus River, 207.
Agusan-Davao district, 234.
 Valley, 205.
Alabaster, 334.
Albay hot springs, 102.
Albite, 334.
Alcyonaria, 138.
Alpaco (upper Miocene), 83
Altaite, 335.
Alum, 335, 358.
Aluminum ores, 335.
Alveolina, 317.
Alveolinella, 318.
Ambil, 258, 259.
Ambos Camarines springs, 102.
American mining legislation, period of, 471.
Amethyst, 251, 335, 384.
 from Palawan, 251.
Amphibole, 335, 360.
Amphistegina cf. mamillata, 318.
 niasi, 319.
Amugis, 548.
Anabantidæ, 43.
Analcite, 96, 335.
Anamirta cocculus, 328
Andesine, 335.
Andesites, 94.
Andradite, 335.
Angat iron-ore deposits, 117.
 River, 117.
Anisoptera thurifera, 328.
Anonaceæ, 41.
Anorthite, 335.
Antecedent streams, 146.
Anthophyllite, 335.
Ants, 44
Anubing, 549.
Aonyx cinerea, 42.
Aparri, Luzon, 66.
Apatite, 335.
Aperient waters, 401.
Apitong, 40, 544, 548.
Apocynaceæ, 41.
Apo district, 232.
 Island, 255.
 volcanic cluster, 217
Appendix, 537.
Aragonite, 335.
Arca, 86.
 cf. barbata, 329.
 cf. coelata, 315.
 cornea, 315, 325, 329.
 ferruginea, 315, 325, 329
 granosa, 315, 330.
 nodosa, 236, 324
 tenebrica, 315.
 sp., 325.
Architectonica pictum, 314.
Arctictis whitei, 42.
Argus Mining Co., 422.
Arkose, 103.
Aroroy district, Masbate, 119.
Arsenic, 335.
Arsenical waters, 101.
Arsenopyrite, 336.
Artesian wells, 400.
Arthropods, 44.
Artocarpus sp., 549.
Asbestos, 336, 358-360, 553.
 mining methods, 360.
 origin and occurrence of, 359
Ascension mines, 435.
Ascent of Mount Apo, 29.
Asiatic basin, 319.
 continental platform, 18.
Aspergillum annulosum, 325.
Asphalt and bituminous limestone, 553.
Asphaltum, 336.
Astraea, 235, 256.
Astraeopora sp., 326
Astrea, 87, 90.
Atas, 232.
Atimonan Road, 51.
Atolls, 57, 58, 248.
Augite, 336.
Ayoni anticline, 388.
Azurite, 336.

B

Babuyan Claro, 304.
Babuyanes Islands, 261.

Bacau stage, 80–82.
Bago River, 159.
Bagobos, 232.
Baguio, mining district, 426.
Plateau, 52, 126, 130.
Balabac Island, 249.
Balanophyllia sp., 329.
Balanus sp., 324.
Balbalasang Trail, 51
Baltimorite, 336.
Bambungan springs, 403.
Bancas, 442.
Banisilan formation, 328, 331
Banlasan, 441.
Barbatia fusca, 315.
Barite, 336.
Barometric pressure, 37.
Barrier reefs, 57, 58.
Baruyen formation (radiolarian chert and jasper), 71.
Basal conglomerate, 76.
Tertiary, 77.
Basaltic and andesitic flows and agglomerates, 92.
Basalts, 96.
Basement complex, 71
Bashi Channel, 267.
Islands, 262.
Basilan, 220, 244.
Basonite, 336.
Bastite, 336.
Bat guano on Marinduque, 150
Batan, 78, 320, 366.
coal, 320, 366.
coal measures, 60.
formation, 78.
Batanes Islands, 261.
Batangas springs, 402.
Batea, 468.
Batete, 549.
Batomys, 42.
Batong-buga, 455
Batrachians, 43.
Bats, 42.
Batwaan caves, 199.
Bayombong-Echague Trail, 51.
Bees, 44.
Beilschmiedia cairocan, 328.
Bench gravels, 91.
Benguet Consolidated gold mine, 351, 409, 411, 412, 427–432, 470, 557, 558.
Consolidated mining and milling costs, 557.
Consolidated Mining Co., 351, 470.
Consolidated mining supplies cost comparisons, 558.
quartz diorite, 98.
Road, 64, 118, 127.
Beryl, 336.
Bibliography of Philippine geology, paleontology, geography, mineralogy, and related subjects (1574 to 1921), 478–519.
Bicol River, 117.
Bicols, 196.
Bilingan, 441.
Biliran, 189, 397.
sulphur deposit, 397.
Binabay River (Mindoro) placers, 443
Binalbagan River, 159.
Binalonan, Pangasinan, 435.
Binangonan limestone, 310.
Biotite, 337.
Birds, 42.
Bisucay, 253.
Bitumens, 337, 389.
natural, 337.
Bituminous coal, 337.
rock, 361.
Black coral, 44.
Blende, 337.
Bohol, 152, 195
Bongao, 247.
Bornite, 337.
Bothryocampe, 72
Braislakite, 337.
Brass, 333.
Breccia stage, 67, 76.
Bromide and iodide waters, 401.
Bronzite (enstatite), 337.
Bua mine, 432.
Bubalus mindorensis, 41, 257.
Bud Dajo, 246, 307.
Bued River, 118.
River Gorge, 51.
Buildings that may withstand earthquakes, 287.
Bukidnon district, 241.
Plateau, 201, 208, 212
Bukidnons, 178, 205.
Bulacan springs, 402.
Bulla ampulla, 323.
Bullaria ampulla, 320.
Bulusan Volcano, eruption of, 305.
Burdigalian stage, 318.
Busuanga, 249, 255.
Bytownite, 337.

C

Cabanatuan–Dingalan Bay Trail, 51.
Cabra, 258.
Cagayan arc, 20.
basin, 139.
de Misamis placers, 439.
River, 116, 207.
Sulu, 244.
Caingin, 179.
Calamansanay, 549.
Calambayanga iron ores, 460.
Calamian Islands, 253.
Calcite, 337.
California Earthquake Commission investigations, 288.
Calliostoma sp., 328.
Calophyllum blancoi, 328.
Camaching iron-ore deposit, 448.
Camarines iron deposits, 451–454

Camiguin, 264, 305.
Island, 268.
Volcano, 306.
Camisa de bacal, 448.
Camote-Clayton mine, 433.
Cancellaria crenifera, 314.
elegans, 314.
oblonga, 328.
Cancer, 84.
Canguinsa formation, 188, 313, 321.
sandstone, 82, 324, 387.
Canlaon Volcano, 166, 303.
Cansuran River mining district, 442.
Cantabro-Filipino Co., 406, 407, 472.
Capulus sp., 328.
Caramoan Peninsula, 145.
Carbonated waters, 401.
Cardita antiquata, 315, 325, 329.
pica, 329.
Cardium, 86, 315.
attenuatum, 315.
unicolor, 315, 329.
sp., 137, 323, 325.
Carpenteria limestone, 321.
Carpomys, 42.
Cassidaria, 314.
sp., 137.
Cassis sp., 329.
Cassiterite (stream tin), 337.
Cattle, 42.
Cave dwellers near Palawan, 254.
Cebu, 65, 79, 152, 189–194, 320, 367, 391.
coal, 194, 320, 367, 462
coal mines, 462.
coastal plain, 192.
coves, 191.
economic deposits, 194
geologic formations, 192.
geology, 192.
intermediate uplands, 191.
lead, 194.
limestone, 80, 194.
petrography, 193.
petroleum, 194, 391.
physiography, 190.
Portland Cement Co., 361
rise of, 331.
springs, 402.
stratigraphy, 79.
structure, 192.
Toledo Road, 51
uplands, 191.
Celaenomys, 42.
Celtis sp., 549.
Cement, 361.
Cenosphaera, 72, 183.
affinis, 312.
disseminata, 184.
minuta, 184.
Central cordillera of Cebu, 191.
Knot, 20, 50, 126, 145.
plain of Luzon, 123.
plain of Panay, 178.
Centrum theory of Mallet, 270.
Cerithidea cf. ornata, 314.
near dohrni?, 314.
sp., 328.
(Pyrazus) cf. sulcatus, 314.
Cerithium bandongensis, 314, 316.
jenkinsi, 314, 316, 320, 386
jonkeri, 329.
herklotsi, 314, 316, 320, 323
moniliferum, 314.
sp., 320, 324.
Chalcanthite, 338.
Chalcedony, 338.
Chalcocite, 338.
Chalcopyrite, 338.
Chalybeate waters, 401.
Chama sp., 329.
Chanos chanos, 43.
Charcharodon arnoldi, 91, 257.
Chartered cities, 539.
Cherts, 105, 338.
Chevrotain, 41.
China Sea Graben, 18.
Chinese pottery, 420, 468
Chione ?, 315.
chlorotica, 315
lacerata, 320
sp., 329.
Chlorite, 338.
Chromite, 338, 401.
Chrotomys, 42.
Chrysoprase, 338.
Chrysotile, 338, 360.
Cinnabar, 339.
Circle of Fire, 70, 115, 293.
Cities, location and growth of, 61
Classification of igneous rocks, 225
Clastic rocks, 102.
Clay, 174, 188, 362–364.
and clay products, 362.
and shale samples in Bureau of Science geologic collection, 364
Clementia hyalina, 315.
papyracea, 315, 330
sp., 323.
Climate, 34.
Masbate, 196.
Mountain Province, 132.
Negros, 162.
types of, 35.
Cloudiness, 37.
Clypeaster sp., 325.
Coal, 68, 70, 112, 155, 172, 187, 194, 197, 199, 231, 237, 256, 257, 316, 320, 339, 354, 363, 366, 367, 369–377, 381–383, 461, 462, 470, 541, 551.
at the Wray mine, quality of, 371
bituminous, 339.
crystallized, 339.
deposits in Mindoro, 257.
leases, 551.
measures, 60, 68, 77–80, 155, 366, 372, 378, 379.
mine of United States Army, 366.
on Batan, 366.

Coal—Continued.
on Cebu, 194, 367.
on Cotabato Creek, 237.
on Masbate, 197, 199, 372.
on Mindoro, 373.
on Negros, 155, 172.
on Polillo, 370.
on Semirara, 256.
on Sibuguey Peninsula, Mindanao, 369.
revocable permits, 551.
seams and inclosing beds, 376.
Coast and Geodetic Survey in the Philippines, work of, 30.
line of Negros, 158.
line of Sulu Archipelago, 215.
Coastal plain of Cebu, 192.
plain of Lubang, 258.
plain of Mindanao, 201.
plain of Negros, 156.
plains, 25, 54, 156, 192, 201, 258.
plains, lack of, 54.
Cœlenterata, 329.
Cogon, 40.
Coke, 363.
Coking coal, 370, 374, 461.
Colorado gold mine, 409.
Mining Company, 425, 426, 470.
Columbella bandongensis, 314.
Comillas springs, 403.
Composition of Central plain of Luzon, 123.
of coal from Escalante, Negros, 172.
Conditions affecting the mining of Philippine coal, 382.
Conglomerates, 138.
Contents, 7.
Continuity of Cagayan de Misamis placers, 440.
Conus, 231.
hardi, 314.
insculptus, 328, 330.
lividus, 314, 328.
loroisii, 314.
ornatissimus, 314, 386.
ornatissimus (var.), 325.
striatellus, 314.
sp., 137, 314, 320, 323, 328.
Copalite, 339.
Copper, 199, 268, 339, 404–406, 408, 409, 471, 472, 553.
deposits, 405, 408.
market, 409.
method of working and smelting, 406.
on Masbate, 199.
production, 472.
silicate in Batanes Islands, 268.
Coral formation, Apo, 255.
limestone, 395.
reefs, 44, 56, 57, 87, 89, 90, 92, 203, 217, 324, 325.
reefs near Baguio, 87.
Coralline forms, 329.
limestone, 253, 322, 325, 326, 327, 331.
Corals, 44, 59, 77, 322, 332.
of Vigo group, 322.
Corbula, 319.
scaphoides, 330.
socialis, 315, 386.
sp., 329.
Cordillera Central, 20, 23, 49, 50, 126, 129, 145, 148, 186, 187, 288.
of Mindanao, 213.
Cordilleras and plains, 121.
Correlation of the Aroroy geologic formations, 198.
Corundum, 253, 339, 384.
reported from Bisucay, 253.
Costs of mining and marketing Philippine coal, 383.
Cotabato, Mindanao, 66, 229.
plain, 202.
River, 204, 205.
Covellite, 339.
Coves of Cebu, 191.
Crater lakes, 244, 248.
lakes of Cagayan Sulu, 244
Cretaceous, 67.
rocks, 312.
Crocoite, 339.
Crystalline rocks, 251.
Cubi, 549.
Cudiapi sandstone, 82, 83, 86, 322–324
Cuencas, 191.
Cuesta topography, 146.
Culion, 249, 254.
leper colony, 254.
Cuprite, 339.
Curuon (Mindanao) placers, 444.
Cuyo, 248, 249.
Islands, 253.
Cycloclypeus communis, 318, 319, 321.
Cyclolites, 84.
Cyclonassa elegans, 314, 329.
Cycloseris sp., 329.
Cynocephalus volans, 42.
Cyperaceæ, 328.
Cypraea, 231.
cf. tigris, 314.
erosa, 328.
sp., 314, 320, 324, 328.
Cyprinidæ, 43.
Cytherea, 86, 323.

D

Dacites, 97.
Dagupan, Luzon, 65
Dalag, 176.
Danao Coal Mines, Limited, 369.
Danau formation, 69, 73.
Dao, 548.
Dapanas placers, 441.
Davao upland, 211.
Deccan Plateau of India, 70.
Dedication, 3.
Delphinula, 314.
reeviana, 314.
Demonstration mine, 435.
Development and arrangement of mountains, 49.
Diallage, 339.

Diamonds, 333.
Diastrophism, 45.
Dictyomitra, 72, 183.
affinis, 183.
tenuis, 312.
Didicas Rocks, 264, 304.
Diopside, 340.
Diorite, 98, 99, 131.
porphyry, 98, 100.
Diplodiscus paniculatus, 328, 549.
Dipterocarpaceæ, 40, 41, 328.
Dipterocarpus affinis, 548
grandiflorus, 548.
Directory of mine operators in the Philippine Islands, 552–556.
Distortio clathrata, 314, 328.
Distribution of clays, 363.
of the population of Panay, 178.
of de Vigo, 82.
Dolium, 84.
costatum, 325.
sp., 328.
Dolomite, 340.
Dormant volcanoes, 50.
Dosinia cf. lenticularis, 315
cretacea, 315.
variegata, 325.
sp., 138, 323.
Draco, 43.
Dracontomelum dao, 548.
Drillia sp., 314.
Dugcalon placers, 441.
Dune lakes, 55, 56.
Dungon, 546.

E

Early workers in Philippine mining fields, 474–476.
Earthquake map of Philippines, 280.
Earthquakes in Agusan Valley, 276.
in Batanes Islands, 267.
in Benguet Subprovince, 276.
in Camguin, 274.
in Masbate, 198.
in Nueva Vizcaya, 275.
in the Philippines, 120, 198, 267, 272, 274–276, 284–288, 295, 297.
practical considerations, 287
East Batan Coal Co., 470.
Eastern Cordillera, 139.
Mining Co., 420.
Eburna ambulacrum, 314
Echinoid spine, 329.
Economic deposits of Agusan-Davao district, 236.
deposits of Cebu, 194.
deposits of Cotabato, district, 231.
deposits of Lanao district, 229.
deposits of Palawan, 251.
deposits of Panay, 184.
deposits of Surigao district, 240.
geology, 351.
geology of Batanes Islands, 268.
geology of Lubang Islands, 260.
Economic—Continued.
geology of Negros, 167.
minerals on Luzon, 148.
minerals of Masbate, 199.
Effects of modern improvements, 66
Elevated coral reefs, 89.
Emerald, 336, 340.
Empusa, 44.
Enargite, 340.
Endemism of Philippine flora, 39
Enstatite, 340.
Eocene, 67, 312.
limestones, 310.
marine deposits, 60.
Eogene, 317.
Epidote, 340.
magnetite schist, 107.
Epistilbite, 340.
Eruption of Mount Mayon, 302.
of Taal Volcano, 271, 273, 274.
Eruptions of volcanoes on Babuyan Claro, 304, 305.
Eulima sp., 328.
Euphorbiaceæ, 41.
European basin, 319.
Explosion crater lakes, 55, 56.
Extrusive rocks, 50, 250.
Extrusives, 135.

F

Faulting, 19, 24, 113, 125, 380.
Fauna of the Malumbang formation, 322.
Favia sp., 326.
Feldspar, 340.
Felis minuta, 42.
Fibrolite, 340.
Ficus reticulata, 314.
Filipino-American mining legislation, period of, 474.
mining legislation, period of, 474.
Fishes, 43.
Flabellum cf. australe, 329.
Flint, 340.
Flora, 39.
Folding, 19, 24.
Foraminifera, 68, 69, 310, 316, 317, 321, 379.
Foraminiferal limestone, 105.
rocks, 321.
Forest conditions in Aroroy district, Masbate, 545.
Foreword, 5.
Formation of the great lakes, 73
Formosan minerals, 334.
Fossil clams and snails, 311.
collections, 320, 323–326, 328, 330.
corals, 77.
flora in Luzon, 113.
leaves, 52, 88, 89, 137, 327.
shells, 180, 236.
shells on Panay, 180.
Fresh-water fishes, 43.
Friar lands, 31.
Fuel supply for blast furnaces, 461.

Fungia decipiens, 137.
sp., 325.
Fusinus sp., 320.
Fusus sp., 323.

G

Gabbros, 100.
Galaxaea sp., 326.
Galena, 340, 465.
Carnet, 340.
Gastropoda, 314, 320, 328.
Gems, 384.
General and economic geology of the districts of Mindanao, 219.
character of Cagayan de Misamis placers, 440.
geology of Lubang, 258.
geology of Mountain Province, 133.
geology of Panay, 179.
world conditions in relation to mining, 355.
Geography, 26.
and physiography of Lubang Islands, 258.
of Zamboanga district, 220.
Geology agents, 45.
factors affecting coal mining, 380.
formations in Cebu, 192.
history, 111, 186, 198, 247.
history of Leyte, 186.
history of Masbate, 198.
history of Sulu Archipelago, 247.
problems in the Philippines, 33.
Geological age of rocks, 309.
conditions, 356.
Geology, Agusan-Davao district, 234.
Apo district, 232.
Apo Island, 255.
Aroroy district, 421.
Baguio mining district, 427.
Babuyanes, 261.
Balabac, 249.
Basilan, 244.
Batanes, 261, 263.
Bohol, 195.
Bukidnon district, 241, 242.
Cagayan Sulu, 244.
Calamian Islands, 253.
Cebu, 192.
Cotabato district, 229
Cuyo Islands, 253.
Lanao district, 227.
Lubang Islands, 258
Luzon, 147.
Malindang district, 226.
Masbate, 195, 197.
Mindanao, 200–244.
Mindoro, 256.
Negros, 164.
Palawan, 250.
Palawan-Cuyo-Mindoro group, 248.
Romblon, 200.
Samar, 153.
Semirara, 256.
Sibuguey Peninsula, 228.
Geology—Continued.
Sibuyan, 200.
Sulu Archipelago, 245.
Surigao district, 236, 240.
Tablas, 200.
Tiruray district, 232.
Zamboanga district, 220.
Gesneraceæ, 41.
Glacial control, 58.
Globigerina, 91, 183, 318, 386.
Glossary of Philippine mining terms, 559.
Glycimeris angulatus, 315, 329.
viteus, 315.
sp., 325.
Gold, 187, 243, 244, 251, 260, 268, 341, 409, 413–415, 441, 445, 467, 468, 552.
bearing veins in the Philippines, 413–415.
in Batanes Islands, 268.
method employed for recovery of, 441.
production, 445.
reported from Bukidnon district, 243, 244.
reported from Lubang Islands, 260.
reported from Palawan, 251.
Golden statuette found in Mindanao, 168.
Golo, 258, 259.
Gophering, 382.
Gradation, 46.
Grahamite, 341
Gramineæ, 41.
Granite, 102, 131.
Granitic batholiths, 49.
Graphite, 341.
Gravel, 394.
Gregarious forests, 10.
Ground water on Negros, 160
Guadalupe formation, 87
stone, 395.
Guano, 146, 341, 384
Guide fossils, 316.
Guijo, 547.
Guild of Mestizos, 471
Guttiferæ, 41, 328.
Gypsum, 341, 384

H

Hagachac, 548.
Halite, 341.
Haminea, 314.
Harpa articularis, 314.
Hayes mine, 421.
Headwaters mine, 133.
Hematite, 341.
Hepatic waters, 401.
Highland plateaus, 52.
Hison iron-ore deposit, 449.
History of Aroroy mine workings, 420.
of mining in the Philippine Islands, 467.
of mining legislation in the Philippine Islands, 473.
of Paracale–Mambulao gold field, 412.
Horizon determiners, 316.
Hormas, 456.
Hornblende, 341.
andesite, 95.
Hospital Hill slide, 127.

Hot springs of Negros, 167, 175.
Huckleberry, 40.
Human response to physiographic conditions, 61.
Humidity, 36.
Hyacinth, 341.
Hydrography of Luzon, 116.
of Mountain Province, 132.
of Negros, 158.
Hygiene, 357.
Hypersthene, 95, 341.

I

Ibujos Island, 263.
Iddingsite, 342.
Ifugao, 133.
Igneous rocks, 68, 71, 93, 97, 149, 164, 165, 174, 179, 180, 224, 225, 239.
Igorot burial caves, 136.
Igorots, 62, 133.
Illustrations, 9.
Ilmenite, 342.
Ilocanos, 61, 126.
Ilocos Asbestos Products Co., 359.
coast strip, 126.
Ilog River, 159.
Iloilo, Panay, 65, 402.
springs, 402.
Imperata, 133.
Important earthquakes, discussion of, 284.
Imports of mineral waters, 399.
Incised meanders of streams on Negros, 157.
Index, 521.
Infanta-Tanay Trail, 51.
Inferior courts, 539.
Inglesa, 456.
Insects, 44.
Insular Government, 537, 538.
Intermediate uplands, 54, 146, 191, 208
uplands of Cebu, 191.
uplands of Mindanao, 208.
Intermontane plains, 25.
Introduction, 15.
Iponan River, 207.
Iridium, 342.
Iron, 174, 241, 446, 448, 450, 451, 455-458, 460, 461, 463, 470, 553.
and steel products imported into the Philippine Islands 463.
deposits near Santa Inez, 451.
ore of Surigao district, 241.
smelting in the Philippines, 455-458.
Irregular coast line, 48.
configuration of the Philippine Archipelago, 48.
Irrigation in the highlands, 62.
Isbayat, 263.
Islands composing the Philippine Archipelago, 26.
Isuan, 399.
Itogon springs, 403.

J

Jamesonite, 342.
Jasper, 342.
Java, stratigraphy of, 67.
Javanese colonization in the Philippines, 27.
fossils, 331.
gold miners, 168.
Jolo, 245, 246.
arc, 20.
Joncoy, 456.
Judiciary, 539

K

Kaal formation, 74.
Kalinga, 133.
Kalinite, 342.
Kaolin deposits, 363.
Kaolinite, 342.
Kelly mines, 433, 434.
Keystone Mining Company, 122.
Kiangan springs, 403.
Kingiodendron alternifolium, 549.
Klondike springs, 403.
Koordersiodendron pinnatum, 548
Kulingtang-Buldung Range, 216.

L

Labor costs, 382.
Labradorite, 342.
Lagenum multiforme var. tayabum, 323
sp., 325.
Laguna de Bay, 119.
de Bombon (Taal), 120, 300.
springs, 402.
Lake Balinsasayao, 176
Balut, 215.
Bato, 121.
Bombon, 120, 300
Buluan, 214.
Cagayan, 121.
Canaren, 121.
Dapao, 215.
Kadagan, 215.
Lanao, 214.
Lanao upland, 210.
Leonard Wood, 215.
Liguasan, 214, 215
Linao, 215.
Mainit, 215, 239.
Malanao, 215.
Munay, 215.
Nonungan, 215.
Paoay, 121.
Taal, 215.
Lakes, 55, 119-121, 176, 210, 214, 215, 239, 300, 402.
and swamps of Luzon 119.
of Mindanao, 214.
Lalang grass, 40.
Lanao district, 227.
Lanatin iron deposits, 450.
Landslips, 59.
Land-subsidence lakes, 55.
Lapac, 247.
Late igneous rock on Sibuguey Peninsula, 224.
Laterite, 47, 91, 225.
Latirus madiunensis, 329, 330.
Lauan, 40, 544, 546.

Lauraceæ, 41, 328.
Lava-dam lakes, 55.
Law relating to coal lands, 541.
relating to metal mines, 541.
Lead, 148, 194, 199, 342, 464, 553.
on Cebu, 194.
on Marinduque, 148.
on Masbate, 199.
zinc, and copper, 553.
Legaspi, Luzon, 66.
Leguminosæ, 41, 544.
Leiconcha trimaculata, 329.
Leper colony at Culion, 254.
Lepidocyclina, 68, 77, 79, 154, 222, 250, 310, 311, 313, 316, 317, 320, 322.
dilatata, 319.
fauna, 321.
formosa, 318, 319, 321.
inermis, 318.
inflata, 318.
insulae-natalis, 318, 319, 379.
limestone, 80, 249, 318, 321.
limestone facies of the Vigo group, 316.
monstrosa, 321.
proemarginata, 317.
richthofeni, 80, 318, 319, 379.
smithi, 317, 319.
tournoueri, 319.
verbeeki, 312, 313, 318, 319.
(Nephrolepidina) angulosa, 321.
(Nephrolepidina) verbeeki, 318.
Leucaena glauca, 462
Leucite, 342.
Leucitic rocks, 96.
Leucozia unidentata, 325.
Leyte, 152, 185, 186, 388, 394, 397.
Asphalt & Mineral Co., 389.
Asphalt and Mineral Oil Co., 361.
geologic history, 186.
natural bitumens, 394.
petroleum, 388.
sulphur deposit, 397.
Lianga placers, 448.
Light, 37.
Lignite, 342.
Lima sp., 329.
Lime, 170, 385
and phosphates, 170.
Limestone, 52, 79, 80, 105, 135, 194, 237, 249, 253, 264, 310, 318, 321, 322, 326, 327, 331, 359, 395, 553.
cave on Coron Island, 253.
from the Benguet Road, 105.
of Cebu, 194.
terraces, 264.
Limonite, 343, 385.
Limopsis multistriata, 325.
Linear disposition of volcanic islands in the Pacific, 291.
Lithia waters, 401.
Lithothamnion ramosissimum, 324, 327.
Lithothamnium, 87, 250.
ramosissimum, 105, 136, 197.
Lizards, 43.
Lode claims, 541.
patents, 550.
Lodestone, 343.
Log of a well at Arayat, Pampanga, 125.
Lower Miocene, 67.
Tertiary, 67.
Lubang, 249, 258, 260.
Islands, 258.
sand and gravel, average composition of, 260.
sand used for core making, 260.
Lucina sp., 320, 329.
Luzon, 113, 115, 116, 124, 147, 148, 278.
economic deposits, 148.
fossil flora, 113.
geology, 115, 147.
Gold Co., 439.
hydrography, 116.
origin of central plain, 124.
physiography, 115.
rivers, 116.
seismic regions, 278.
Luzonite, 343.

M

Macino, 242.
Macoma nobilis, 329.
sp., 325.
Madrepora, 255, 256.
duncani, 322.
Maeandrina, 255, 256, 326
Magalipac, 548.
Magatalisay, 549.
Magellan in the Philippines, 27.
Maglihi anticline, 388
Magma mine, 435.
Magnesia alum, 345.
Maghesite, 343.
Magnetic surveys, 29
Magnetite, 343.
schist, 107.
Magnetized iron ore, 343.
Mainit spring, 404.
Mait, 468.
Malachite, 343.
Malaguibuyo, 549.
Malaicmo, 549.
Maliit gold mines, 418
Malindang district, 226.
Malipa anticline, 388.
Malitabug River, 203.
Malumbang corals, 322, 325.
formation, 165, 320, 322, 325.
formation, Pliocene, 85.
limestone, 52, 80, 359.
series, 85.
Mambulao gold mines, 417.
Mammals, 41.
of Mount Data, 42.
Mandayas, 205, 212, 214.
Manganese, 169, 464.
effect of, on sugar cane, 169.
Manganite, 343.
Mangelia, 314.
Mangguañgans, 205.

Mangrove swamps, 549.
Mangyans, 257.
Manila Iron & Steel Co., 457.
Luzon, 64.
price of Chinese "slack," 383.
Manis javanica, 41.
Manobos, 205, 210, 232.
Mapania numilis, 328.
Maps issued by the Spanish mining bureau and the Division of Mines, Bureau of Science, from 1886 to 1914, 32.
Marble, 108, 200, 343, 395, 555.
ornamental, 555.
Romblon, 200, 395.
Marcasite, 343.
Margarite, 344.
Marginella, 314.
Marilao springs, 402.
Marinduque, 148–151.
agriculture, 149.
bat guano, 150.
lead, 148.
mineral deposits, 150, 151.
natural gas, 150.
stock raising, 149.
transportation on, 149.
Marine conglomerate, 90.
gardens, 44.
invertebrates, 43.
terraces, 154, 331.
terracing on Samar, 154.
Market for Philippine coal, 383.
Marl, 136.
Marly stage, 67.
Marobo, 549.
Marongas, 247.
Masbate, 153, 195–200, 372, 545.
climate, 196.
coal, 197, 199, 372.
copper, 199.
earthquakes, 198.
economic minerals, 199.
forest conditions, 545.
geologic history, 198.
geology, 195, 197.
lead, 199.
neolithic remains, 200.
population, 196.
rainfall, 196.
topography, 196.
Mataling River, 207.
Matobato, 549.
Mayapis, 40.
Mayari iron ores, 460.
Mayon Volcano, 307.
Meandrina, 90.
Melaconite, 344.
Melanaxis, 41.
Melania asperata, 314.
sp., 323.
Melastomataceæ, 41.
Meliaceæ, 41.
Menispermaceæ, 328.
Mercury, 344.
Mesetas, 191.
Mesozoic fossils, 332.
(?) sediments, 71.
Messina earthquakes, 270.
Metadiorites, 100.
Metallic minerals, 268, 404.
minerals of Batanes Islands, 268.
Metals, 70.
Metamorphic rocks, 24, 105, 147, 250.
Metis sp., 325.
Meycauayan stone, 395.
Mica, 106, 344, 385.
and micaceous schists, 106.
Middle Miocene, 68.
Minas de Batan, 366.
de Batan Co., 470.
Mindanao, 200, 201, 206, 208, 213, 214, 216, 217, 219, 220, 277, 389, 468.
coastal plain, 201.
cordillera, 213.
intermediate uplands, 208.
geology, 219.
gold deposits, 468.
golden statuette, 468.
lakes, 214.
petroleum, 389.
plains, 201.
population, 201.
rainfall, 214.
rivers, 201, 206.
seismic regions, 277.
stratigraphic scheme, 220.
terraces, 217.
volcanoes, 216
Mindoro, 248, 249, 256, 257, 369, 373, 392.
coal, 257, 369, 373.
geology, 256.
oil seeps, 257.
petroleum, 392.
placer mining, 257.
sugar plantation, 257.
Mineral collections, 333.
deposits on Marinduque, 150, 151.
development in the Philippine Islands, factors affecting, 354.
lands and mine operators, 550.
lands segregated from the public domain, 550.
production for the Philippine Islands, 352.
products of the Philippines, 351.
resources of Leyte, 187.
waters, 399, 555.
Minerals in Negros soils, 168.
of Basilan, 226.
Mineralogy, 333.
Mining Bureau, staff of, 16.
costs, 356, 461, 557.
Filipinos prohibited by Spaniards from, 469.
in the Philippines, 351.
laws and regulations, 355.
methods in the Philippines, 382.
personnel, 357.
taxes, 356.

Minium, 344.
Miocene, 313.
beds, 78.
deposits, 321.
Revolution, 19, 112.
rocks, 313.
tuffs, 310.
Miogypsina, 317–319, 321.
irregularis, 318.
Miscanthus, 133.
Miscellaneous mineral products, 542.
placer districts, 445.
Mitra bucciniformis, 314, 316.
javana, 91, 314, 316.
jenkinsi, 314, 316.
junghuhni, 314, 316.
sp., 323.
Modiolus sp., 325.
Molave, 547.
Molybdenite, 344, 465.
Montalban Gorge, 144.
Montamorong iron-ore deposit, 448.
Montescos, 63.
Monteses, 441.
Monthly distribution of earthquakes and rainfall at Manila and at Butuan, 290.
distribution of Philippine earthquakes and rainfall, 289.
Moraceæ, 41.
More-important properties of the Aroroy district, 421.
Moros, 201–208, 210, 232.
Mountain passes and trails, 51.
Province, 129, 403.
Province springs, 403.
Mount Apo, 29, 293–295.
Apo, ascents of, 29, 294.
Apo, history of, 295.
Apo, sulphur vents on, 295.
Arayat, 306.
Caua (Cagua), 305.
Mayon, 301.
Mirador limestone, 326.
Pelee disaster, 299.
Uling Coal Mining Co., 368.
Mouse deer, 41.
Mungos palawanus, 42.
parvus, 42.
Municipal government, 538.
Murex capucinus, 330.
cf. pliciferas, 328.
endivia, 314.
microphyllus, 329.
verbeeki, 330.
Muriated waters, 401.
Muscovite, 344.
Myrtaceæ, 41.
Mytilus sp., 325.

N

Naga, Luzon, 66.
Naguilian Road, 51.
Narra, 548.
Nassa canaliculata, 314, 329.
costellifera, 314.
crenulata, 314, 328, 329.
dispar, 314.
gemmulata, 314.
globosa, 329.
globosa minor, 314.
quadrasi, 314.
reussi, 314.
thersites immersa, 314.
thersites leptospira, 314.
sp., 323, 328.
Natica albumen, 314, 328.
cumingiana, 314.
lacernula, 314.
mamilla, 314, 328, 330.
spadicea, 314, 328.
sp., 320, 325.
National Coal Co., 368, 369, 377
Development Co., 361.
Petroleum Co., 473.
Natural bitumens from Villaba, Leyte, physical properties of, 394.
gas, 150, 387.
gas on Marinduque, 150.
Nauclea sp., 549.
Negritos, 63, 141, 142, 178.
Negros, 152, 154–160, 162–164, 167, 168, 170, 172, 174, 175, 396, 404.
climate, 160.
coal, 155, 172.
coast line, 158.
coastal plain, 156.
geology, 164, 167.
ground water, 160.
harbors, 158.
hot springs, 167, 175, 404.
hydrography, 158.
lakes, 159.
minerals, 168.
rainfall, 162, 163
rivers, 159.
settlements, 162.
soils, 168, 170.
springs, 404.
streams, 157.
sugar industry, 156.
sulphur mining, 396.
topography, 155.
water power, 174.
wells, 160.
Neocene, 317.
Neolithic remains on Masbate, 200.
Neovolcanic belt, 266.
Nepheline, 344.
Nephrolepidina, 317, 321.
Nerita funiculata, 314.
Niter, 344.
No Man's Land, 130.
Nonmetallic minerals, 358.
minerals in Batanes Islands, 268.
Norite, 101.
Nueva Vizcaya springs, 404.
Nummulina ramondi, 312.

Nummulites, 77, 222, 310, 312, 317.
niasi, 317.
subniasi, 78, 312, 313, 319.
variolari, 312.
Nummulitic limestone, 79.
Nycticebus menagensis, 42.

O

Oak, 40.
Ocean and harbors of Negros, 158.
Ocher, 344, 385.
Oil arc, 22, 70.
seeps in Mindoro, 257.
Old slates, 108.
Oligocene, 67.
age, horizons of, 313.
deposits, 321.
Oligoclase, 344.
Oliva, 231.
Olivella, 314.
Olivia indet., 323.
sp., 323.
Olivine, 344.
Opal, 345, 384.
Operculina, 105.
complanata, 105, 318, 319.
costata, 323.
costata var. tuberculata, 318.
Ophiocephalidæ, 43.
Ophiocephalus striatus, 176.
Orbitoides, 77, 84, 310, 318.
dispansa, 312.
papyracea, 312.
Orbitolites, 317, 318.
Orchidaceæ, 40, 41.
Ore deposition in the Philippines, 112.
Origin of Central plain of Luzon, 124.
of Philippine placers, 436.
Ornithoptera trojana, 44.
Orthoclase, 345.
Osmium, 345.
Ostrea hyotis, 325.
orientalis, 323.
sp., 315, 329.
Outline of Philippine Government, 537.
Oxbow lakes, 55, 56.
Ozocerite, 345, 387.
veins, 387.

P

Pabirics, 438.
Pachyseris cristata, 322.
Pagatpat, 383.
Pahudia rhomboidea, 547.
Pakil springs, 403.
Palawan, 20, 248–252, 254, 404.
arc, 20.
cave dwellers near, 251.
Cuyo-Mindoro group, 248.
economic deposits, 251.
geology, 250.
gold reported, 251.
salt spring, 404.
subterranean river, 250.
volcanoes, 252.
Paleontology, 309.
Paleozoic fossils, 332.
rocks, 18, 69.
schists, 107.
Palidan Slide, Suyoc, 435.
Palmæ, 41.
Pampanga River, 116.
Panaoan, 189.
Panay, 152, 177–180, 184, 392.
central plain, 178.
distribution of population, 178.
economic deposits, 184.
fossil shells, 180.
geology, 179.
petroleum, 184, 392.
shales, 180.
vegetation, 179.
Pangutaren, 245.
Panique formation, 75.
Pansol springs, 403.
Paphia striata, 329.
textris, 315.
Paquiao system, 382.
Paracale district (lode and placer), 412.
district (placer), 418.
gold district, 76.
gold mine, 409.
Mambulao district, 468.
River, 118.
Paradoxurus, 42.
Paragonite, 345.
Parashorea plicata, 546.
Pasig River, 118.
Pattalophyllia (?) bonita, 322.
sp., 323.
Payason placers, 441.
Pearl oysters, 44.
Pecten, 77, 231.
cf. cristularis, 315.
cf. lentiginosus, 320.
cf. radula, 315.
leopardus, 137, 320, 323–325.
pseudolima, 315.
senatorius, 137, 323, 325.
squamosa, 329.
sp., 323, 325, 329.
(Pleuronectia) pleuronecta, 315.
Pelecypoda, 315, 320, 329.
Pelecypods and gastropods of the Vigo group, sandstone and shale facies, 313.
Peñaranda gold placers, 436, 437.
Pennine, 345.
Penninite, 345.
Peñon de Coron, 254.
Peridotite, 101.
Petrography, 93.
of Cebu, 193.
Petroleum, 70, 184, 188, 194, 231, 248, 345, 385, 387–389, 391–394, 473, 541.
lands, 541.
on Cebu, 194, 391.
on islands of Sulu group, 392.
on Leyte, 388.
on Mindanao, 389.

Petroleum— Continued.
on Mindoro, 392.
on Panay, 184, 392.
on Siasi, 248.
seeps, 387.
Philippine coal, 112.
coal, chemical and physical characters of, 374.
Coal Co., 382.
coal imports, 354.
coal measures, 68.
Coal Mining Co., 366, 367, 470.
coal of Tertiary age, 381.
coal, value of, 374.
coals, analyses of, 375.
deep, 276.
dialects, 38.
earthquakes, 120, 198, 267, 272, 274-276, 284-288, 295, 297.
exploration and cartography, history of, 27.
exports of cement, 354.
exports of chinaware, 354.
exports of coal, 354.
exports of earthen stone, 354
exports of fertilizers, 354.
exports of iron, 354.
exports of salt, 354.
Exposition, 362.
forests and timbers, 543.
fossils, 331.
geology, general features of, 18.
gold production, 409.
imports of cement, 354.
imports of chinaware, 354.
imports of coal, 354.
imports of earthen stone, 354.
imports of fertilizers, 354.
imports of iron, 354.
imports of salts, 354.
iron ore, analyses of, 459.
iron ores, chemical and physical characteristics of, 458.
Legislature, 539.
Mineral Syndicate, 416, 417.
minerals, check list of, 334.
mining laws, 539.
natural bitumens, chemical and physical properties of, 392.
petroleum, paraffin content high, 392.
petroleum, physical and chemical properties of, 392-394.
physiography, 45.
placers, age of, 436.
pottery industry, 362.
rock types, 22.
rocks, analyses of, 110.
seismic disturbances due to displacement, 271.
stratigraphy, Table facing 66.
tectonics, 20.
timbers, 40.
topography, salient features of, 48.
volcanoes, 291.
Philippsite, 345.
Phlogopite, 345.
Phoebe sterculioides, 328.
Phos roseatus, 314.
Phosphates, 384.
Phosphorus content of Philippine iron ores, 459.
Physical condition of soils of Negros, 170.
Physiographic features of Central plain of Luzon, 124.
subdivisions of Cebu, 190.
Physiography of Cebu, 190.
Philippsite, 345.
and geology of Luzon, 115.
of northwest coast of Leyte, 188.
of Samar, 153.
Pickeringite, 345.
Picotite, 345.
Picrites, 101.
Pidatan oil field, provisional stratigraphy of, 230.
Pikit-Banisilan-Lanao Trail, 51.
Digos Trail, 51.
Pink limestone, 237.
Pinna sp., 315, 325.
Pinus insularis, 132, 543.
Pithecanthropus erectus, 89
Pithecus, 42.
Placer claims, 541.
districts, 436.
mining in Mindoro, 257.
patents, 550.
types, 436.
Placer (Surigao) placers, 443.
Placers, 435.
Placuna placenta, 14, 315, 325.
Plagioclase, 346.
Plains of Mindanao, 201.
Platinum, 346, 466.
Pleistocene, 89, 331.
coral reefs, 325.
corals, 332.
limestone, 331
terraces, 332.
Pleurotoma carinata, 323.
tjemoroënsis, 323.
sp., 323.
Plicatula imbricata, 320.
Pliocene, 68.
coral reefs, 324.
limestone, 359.
Plutonic rocks, 50, 164, 250.
Podocrytis, 72.
Poelau Melaioe rock, 73.
Polillo coal, 370.
Political status affects mineral development, 354.
Polypodiaceæ, 11.
Polystomella, 318.
sp., 317.
Population, 38, 133, 196, 201, 221, 261.
Batanes Islands, 261.
Masbate, 196.
Mindanao, 201.

Population—Continued.
Mountain Province, 133.
Zamboanga district, 221.
Porites, 87, 256, 326.
Position of the Philippines relative to other countries, 26.
Possible petroleum localities, 388.
Potash-bearing rocks rare in the Philippines, 96.
Power supply, 462.
Precious metals, 174.
stones, 384.
Preparation of coal for the market, 383.
Pre-Tertiary formations, 181.
intrusives and other rocks, 76.
Prochlorite, 346.
Provincial government, 538.
Provisional stratigraphic scheme of Mindanao, 220.
Proximity of mountains to sea and coastal plains, 54.
Psammobia cf. lessoni, 315.
sp., 315.
Psilomelane, 346.
Pterocarpus indicus, 548.
Pteropus, 42.
Pulangi River, 204.
Pumice in Batanes Islands, 268.
Pustularia nucleus, 328.
Pyrite, 346.
Pyrolusite, 346.
Pyroxene, 346.
andesites, 94.
Pyroxenite, 101.
Pyrula gigas, 324.
Pythons, 43.

Q

Quarternary, 68.
Quartz, 346.
diorite, 98.
mining, 469.

R

Raidolaria, 73, 311, 312.
Radiolarian cherts, 22, 69, 71, 72, 105, 111.
Ragang Volcano, eruption of, 306.
Rainfall, 35, 46, 162, 163, 196, 214.
Masbate, 196.
Mindanao, 214.
Negros, 162, 163.
Ranella, 314.
gyrina, 329.
raninoides, 329, 330.
subgranosa, 236, 314, 328.
tuberculata, 314.
sp., 328.
Realgar, 347.
Recent, 68, 92.
coral reefs, 325.
corals, 332.
Record of bore hole 4, at Butong, Sibuguey coal field, 377.
of well at Janiuay, Iloilo, Panay, 185.
Reefs, fringing, 57, 58.
raised, 59.
Regional geology, 115.
Religious orders in the Philippines, 28.
Remarkable volcanoes, 291.
Reptiles, 43.
Residual bitumens, 385.
Revegetation of Volcano Island (Taal), 301.
Rhodochrosite, 347.
Rhododendron, 40.
Rhynchomys, 42.
Rice terraces, 62.
Richmond Petroleum Co., 385, 386, 388, 173
Ricinula spectrum, 314.
Rio Grande de Mindanao, 204.
River systems, 55.
terraces, 131.
Rivers and lakes of Negros, 159.
north-flowing, 55.
of Luzon, 116.
of Mindanao, 201.
Rizal Cement Co., 361.
Road ballast or metal, 171.
metal, 231.
Rock, 394.
asphalt, 389
Rockfall type of earthquakes, 274.
Romblon, 200.
Rostellaria crispata, 311.
fusus, 314.
Rotalia, 318.
Rubber on Basilan, 211
Rubiaceæ, 41.
Ruby, 347.
Rusa, 41.
Rutile, 347.

S

Sacat, 549.
Saccharum, 40.
spontaneum, 244.
Sagada, 131.
Sahug-Tagum River, 206.
Salt, 347, 394.
Samal Island, 234.
Samar, 152, 153.
geology, 153.
physiography, 153.
San Andreas rift, 270.
Fernando, La Union, Luzon, 65.
Mauricio gold mines, 417.
Sand, 394.
Sandstone, 82, 83, 86, 104, 137, 322, 324, 387.
Sanidine, 347.
Santol mines, 449.
Sapindaceæ, 41.
Sapotaceæ, 41.
Sardines, 43.
Sardonyx, 347.
Schizaster subrhomboidalis, 323, 325.
sp., 324.
Schwab mine, 421.
Sea connection with Europe, 21.
stacks, 248.

Seasonal distribution of earthquakes in the Philippines, 288.
Section of well at Pasay, Rizal Province, Luzon, 124.
Sedimentary rocks, 250.
Seismic disturbances, causes of, 270.
disturbances, types of, 273.
regions in Luzon, 278.
regions in Mindanao, 277.
regions in the Visayan Islands, 277.
Seismology, 270.
Seismotectonic lines, 279
Semirara, 256.
Seraphs sp., 320.
Sericite, 347.
Serpentine, 107, 348.
Settlements and lines of communication on Negros, 162.
Shales, 138, 180.
of Panay, 180.
Sharks, 43.
Shorea guiso, 328, 547.
polysperma, 328.
sp., 328.
Siasi, 245, 247.
Sibuguey coal, 320.
Sibul springs, 402.
Sibutu, 245, 247.
Sibuyan, 200.
Siderite, 348.
Sierra Madre line, 20.
Sigaretus eximius, 328
Silica flux, 462.
Silkworm, 44.
Sillimanite, 348.
Siluridæ, 43.
Silvanite, 348.
Silver, 348, 466.
Sinter, 138.
Situation of Cagayan de Misamis placers, 440.
Small rivers of Mindanao, 206.
Smelting process for producing metallic iron, 462.
Soil of Basilan, 225.
of Cotabato district, 231.
of Lanao district, 229.
of Negros, 168.
Solecurtus quoyi, 315.
Solen sp., 315.
Sorsogon mineral waters, 404.
Southeastern volcanic region, 141.
Southwestern volcanic region of Luzon, 143.
Spanish mining legislation, period of, 473.
Spar, 348.
Sphalerite, 348.
Sphene, 348.
Spisula sp., 315.
Spondylus imperialis, 323, 325.
sp., 315, 329.
Sponges, 44.
Squirrels, 42.
Standard Oil Co., 385, 473
Sterculia blancoi, 548.
Stibnite, 348.
Stock raising on Marinduque, 149.
Stone, 188, 395.
Stratigraphy, 71.
and correlation, 67.
of Cebu, 79.
of Java, 67.
of Sibuguey Peninsula, 223.
of the Cajumay-jumayan coal field, Cebu, 377.
of Zamboanga district, 221.
Stream tin, 337.
Strombosia philippinensis, 546.
Strombus canarium, 314.
(?) fusus, 314.
isabella, 330.
labiosus, 323.
(?) sp., 314.
sp. a, 314.
sp. b, 314.
swainsoni, 314.
Structural geology of Batanes Islands, 265.
Structure of Cebu, 192.
of Philippine Archipelago, 19.
of Sibuguey Peninsula, 224.
Stylosphaera, 183.
Subanuns, 211.
Subsidence, Darwin's theory of, 57.
Subterranean river on Palawan, 250.
Sugar industry of Negros, 156.
plantation in Mindoro, 257.
Sulphated waters, 401.
Sulphur, 167, 173, 187, 261, 269, 348, 395, 396, 399, 556.
deposits in crater of Mount Canlaon, 167.
in Camiguin Island, 261, 269.
mining on Silay, Negros, 396.
on Camiguin (North), 396.
on Mount Apo, 399.
Sulphuretted waters, 401.
Sulu Archipelago, 245, 247, 392.
Archipelago, coast line, 245.
Archipelago, geologic history, 247.
Archipelago, geology, 245.
Archipelago, petroleum, 392.
Supreme court, 539.
Surigao district, 236, 444, 454, 460.
gold mining, 444.
iron deposits, 454.
iron ores, 460.
Mining Co., 443.
Syenite, 102.
Synclinal lakes, 55, 56.
Syndicate gold mine, 409.
mine, brief notes on, 422–425
Mining Co., 420, 422, 470.

T

Taal eruption, 120, 295, 297.
Lake, 120.
Volcano, 295, 307.
Volcano line, 283.
Volcano, maps of crater of, 296.
Tablas, 200.

Tagabilis, 210.
Tagalogs, 142, 143, 196.
Tagalus coarctatus, 236.
Tagoloan River, 207.
Talahib, 40.
Talc, 349, 385.
Tamayuan, 546, 549.
Tangile, 40.
Tapis sp., 138.
Tarrietia sylvatica, 516
Tarsius spp., 42.
Tawitawi, 245, 246.
Taxes, royalties, and rentals, 540.
Tectonic epicenters in Luzon, 278.
Telescopium telescopium, 314.
Tellina, 86.
sp., 315, 325.
Temperature, 35.
Tenorite, 349.
Tentative correlation of the Far Eastern Tertiary, Table facing 68.
Terebra, 314.
bicincta, 314, 316.
javana, 314, 316.
sp., 328.
Terminalia nitens, 549.
quadrialata, 545.
Terraces on Mindanao, 217.
Tertiary, 312.
corals, 332.
geological time scale, 315.
rocks on Sibuguey Peninsula, 223.
Tethys, European, 69.
Tetrahedrite, 349.
Thais spectrum, 314.
Thecurus pumilus, 42.
Themeda, 40.
Thermal waters, 401.
Thunder storms, 37.
Tiangi, 214.
Tide waves, 277
Tila Pass, 51.
Tiliaceæ, 328.
Timarau, 41.
Timber licenses and taxes, 542.
trees, 545.
Tin, 349.
Tindalo, 547.
Tiruray district, 232.
table-land, 208.
Tirurays, 210.
Titanite, 349.
Tiui Hot Spring, 402.
Tonase, 441.
Toog, 545.
Topadas, 441.
Topaz, 349.
Topographic mapping, 31.
Topography of Masbate, 196.
of Negros, 155.
of Sibuguey Peninsula, 223.
Trachytes, 95.
Tragulus nigricans, 41.
Transportation, 356.
on Marinduque, 149.
Travertine, 138, 349.
Tremolite, 349.
Trewia ambigua, 549.
Tridymite, 349.
Trigger effect of changes in barometric pressure, 290.
Trinil beds, 89.
Triton clavator, 328.
pfeifferianum, 314.
Trochus, 314.
niloticus, 44.
sp., 320, 323.
Tropical sunlight, 37.
Tsunamis, 277.
Tubipora, 256.
Tuff, 104, 136.
a typical, 104.
Tujubs, 441.
Tumaga River, 208.
Tumbaga gold mines, 417.
Turbinella junghuhni, 320.
tjidamarensis, 138.
Turbinolia, 242.
Turbo, 231.
borneensis, 137, 228.
marmoratus, 44.
sp., 320, 323, 325.
Turricula bataviana, 330, 331.
Turris carinata, 329.
carinata woodwardi, 314.
coronifer, 314, 316.
deshayesi, 314.
flavidula var. sondc, 328.
garnonsi, 314.
marmorata, 314.
(Surcula) flavidus, 314.
Turritella cinquelifera, 236.
terebra, 329, 330.
sp., 325.
Typhoons, 36.

U

Uling Coal Mining Co., 380.
Umirey River placers, 438.
Uplands of Cebu, 191
Upper Miocene, 68.
Pliocene, 328.
Uralite, 349.
Urticaceæ, 41.

V

Values of Philippine placers, 436.
Vauquelinite, 349.
Vegetation of Mountain Province, 132.
of Panay, 179.
Venus squamosa, 236, 330.
Verbenaceæ, 41.
Vermes sp., 329.
Vermetus javanus, 315, 316, 386.
Vermiculite, 349.
Vertebrate corals, 332.
Vicarya callosa, 79, 180, 222, 310, 314, 316, 319, 320, 322, 326.

Vigo formation, 78, 82, 386.
fossils, 82.
group, 313.
group, partial list of, species from the, 314.
(middle Miocene), 78.
shales, 60, 80, 81.
Villaverde Trail, 51.
Visayan Islands, 152.
Visayans, 63, 179, 205.
Vitex parviflora, 547.
Viverra, 42.
Volcanic areas, 23.
earthquakes, 273.
topography, 47.
Volcanism, 22, 47, 70.
in Batanes Islands, 264.
in Bukidnon district, 243.
in Sulu Archipelago, 246.
Volcanoes, 29, 50, 56, 166, 217, 271, 273, 274, 291, 293–295, 301, 302, 304–307.
of Batanes Islands, 262.
of islands north of Luzon, 303.
of Mindanao, 216.
of Palawan, 252.
Volcanology, 291.
Voluta innexa, 320.

W

Wad, 349.
Water power in Negros, 174.
rights and power sites, 543.
Well at Arayat, Pampanga, log of, 125.
at Pasay, Rizal Province, Luzon, section of, 124.
logs from borings made by the Bureau of Public Works in Negros, 161.
Wells on Negros, 160.
Wernerite, 350.
Western Cordillera, 121.
Whetstone in Camiguin Island, 269.
Wind velocity, 37.
Winds and storms, 36
Wolframite, 350, 466.
Wray coal mine, 371.
Wright-Taft Trail, 51.

X

Xenophora dunkeri, 323.
sp., 323.

Y

Yacal, 40, 544.

Z

Zambales line, 20.
Zamboanga, 66, 211, 220.
formation, pre-Pliocene in part, 85.
Zeolite, 350.
Zigzag, 127.
Zinc, 464.
Zincblende, 350.
Zircon, 350.

APPENDIX

OUTLINE OF PHILIPPINE GOVERNMENT *

The corporate governmental entities through which the functions of government are exercised throughout the Islands are the Government of the Philippine Islands (the Insular Government), the provincial and municipal governments, and the chartered cities.

Insular Government.—The Insular Government, as in the case of the Federal Government of the United States, is divided into the executive, the legislative, and the judiciary branches. At the head of the executive branch is the Governor-General of the Philippine Islands, who is appointed by the President of the United States, by and with the advice and consent of the United States Senate. He is assisted by the department secretaries in the performance of his duties. All the department secretaries, with the exception of the Secretary of Public Instruction, who is the Vice-Governor at the same time and is also appointed by the President of the United States, are Filipinos and are appointed by the Governor-General. The other officials of the Philippine Government appointed by the President of the United States are the Insular Auditor, the Deputy Insular Auditor, and the nine Justices of the Supreme Court.

The executive departments of the Philippine Government and the bureaus, offices, and boards pertaining to each are the following:

Governor-General:
- Bureau of Audits.
- Bureau of Civil Service.
- All other offices and branches of the service not assigned by law to any department.

Department of the Interior:
- Bureau of Non-Christian Tribes.
- Philippine General Hospital.
- Board of Pharmaceutical Examiners.
- Board of Medical Examiners.
- Board of Dental Examiners.
- Board of Optical Examiners.
- Board of Examination for Nurses.
- Board of Dental Hygiene.
- Executive Bureau.
- PHILIPPINE CONSTABULARY (licenses for explosives).
- Metropolitan Water District.
- Public Welfare Commissioner.

* The Outline of Philippine Government was prepared by L. A. Faustino.

Department of Public Instruction:
- Bureau of Education.
- Philippine Health Service.
- Bureau of Quarantine Service.

Department of Finance:
- Bureau of Customs.
- BUREAU OF INTERNAL REVENUE (taxes, rentals, and royalties).
- Bureau of the Treasury.
- Bureau of Printing.
- General supervision over banks, banking transactions, coinage, currency, and except as otherwise specially provided over all funds the investment of which may be authorized by law.

Department of Justice:
- Bureau of Justice.
- Courts of First Instance and Inferior Courts.
- Philippine Library and Museum.
- Bureau of Prisons.
- Public Utility Commission.
- General Land Registration Office.

Department of Agriculture and Natural Resources:
- Bureau of Agriculture.
- BUREAU OF FORESTRY (timber licenses).
- Bureau of Lands (mine registration and surveys).
- Matters pertaining to colonies and plantations on public lands.
- BUREAU OF SCIENCE (geological service).
- Weather Bureau.
- Matters concerning hunting, fisheries, sponges, and other sea products.

Department of Commerce and Communications:
- BUREAU OF PUBLIC WORKS (water rights).
- Bureau of Posts.
- Bureau of Supply.
- Bureau of Labor.
- Bureau of Coast and Geodetic Survey.
- Bureau of Commerce and Industry.

The Executive Bureau and the Bureau of Non-Christian Tribes, both of which are in the Department of the Interior, exercise supervision over the provincial and municipal governments. The Executive Bureau has charge of the so-called regular provinces; and the Bureau of Non-Christian Tribes, of those inhabited by the non-Christian peoples of the Philippines, such as the Moros in Mindanao and the Igorots of the mountain regions of Luzon.

Provincial government.—The Philippine Archipelago is divided into forty-six provinces, thirty-four of which are designated as regular provinces and the remaining twelve as special provinces. The chief executive of a regular province is the provincial governor, who is an elective official. He and two other elective members form the provincial board which constitutes the legislative branch of the provincial government. In the special provinces the provincial governors are appointive officials.

Municipal government.—As the name indicates, this branch of the government has charge of the municipalities or towns. The chief executive

of a municipality is called the municipal president. The municipal council, which is the legislative branch of the municipal government, consists of from eight to eighteen councilors, depending on the size of the municipality. There is a vice-president who substitutes for the president during his absence or disability and who is ex-officio member of the council.

Chartered cities.—There are only two chartered cities in the Philippines; namely, Manila and Baguio.

The legislative branch.—The Philippine Legislature is made up of the Senate and the House of Representatives. Of the twenty-four senators only two—those from the Twelfth District, which is composed of Mountain Province, the City of Baguio, Nueva Vizcaya Province, and the Department of Mindanao and Sulu—are appointed by the Governor-General. All the others are elected by popular vote, as are also the ninety-three representatives, excepting the nine who represent Mountain Province, Nueva Vizcaya Province, and the Department of Mindanao and Sulu.

Judiciary.—The administration of justice in the Philippines is intrusted to the Supreme Court, the Courts of First Instance, the Municipal Courts of the City of Manila, and the courts of the justices of the peace. The Supreme Court, as its name indicates, is the highest entity in the judiciary system. As such, it has an appellate jurisdiction in all actions and special proceedings brought to it from the Courts of First Instance and from other tribunals from whose decisions the law specially permits appeal to the Supreme Court.

The Supreme Court is made up of nine justices; namely, the chief justice and eight associate justices. As a body it sits en banc to transact business. It also sits in divisions for the same purpose, and when it so sits four justices constitute a quorum; hence two divisions may sit at the same time. Decisions of the Supreme Court of the Philippine Islands may be appealed to the United States Supreme Court in certain cases.

Inferior courts.—There is a court of first instance in each province and a justice of the peace court in nearly every municipality.

ABSTRACT OF PHILIPPINE MINING LAWS AND REGULATIONS *

General.—At the present time both the freehold and the leasehold systems prevail in the Philippines. The metals and the quarry products are still located as mining claims according to the provisions of Act of Congress, July 1, 1902, with the amendments by Act of Congress, February 6, 1905, and various acts of the Philippine Commission regarding regulations governing locations, recording, etc.

Coal lands are taken under lease according to the provisions of Act 2719 entitled The Coal Land Act, enacted by the Philippine Legislature and approved by the President of the United States, May 14, 1917. Regulations governing the leasing and development of coal lands in the Philippine Islands were promulgated August 15, 1917.

* These notes, covering the essential legal points in Philippine mining practice, have been criticized and supplemented by Judge F. B. Ingersoll, attorney of Manila, who has had longer practical acquaintance with the subject than any one else in the Philippines. I am glad to acknowledge this assistance.

Petroleum lands are taken under lease under the provisions of Act 2932 of the Philippine Legislature, as amended by Act No. 3054, approved May 22, 1922, and according to regulations issued by the Secretary of Agriculture and Natural Resources, approved by the Council of State October 13, 1920, and amended in June, 1921, and again in February, 1922.

At the present time a complete new mining act, which proposes to bring all mineral deposits under the leasing system, is being drafted and it may be passed by the Philippine Legislature before this book is printed.

The chief bone of contention in matters of Philippine mining law to-day is the reassertion by the Filipinos, through the Philippine Supreme Court, a majority of whose members are Filipinos, of the Regalian Doctrine; that is, that all mineral deposits, wherever found, whether in the public domain or in land of private ownership, belong to the State (literally to the king). Without discussing the merits of the question I believe that the matter will not be settled short of the Supreme Court of the United States, since the Act of Congress of July 1, 1902, is involved. As that body was not clear in its wording of that part of the Act relating to mining it cannot be definitely asserted, but only conjectured, whether it did or did not mean to reaffirm the principles of the American mining law, which rejects the Regalian Doctrine.

The principal provisions of these various acts and regulations are outlined below.

Prospective petroleum companies must comply with the provisions of Act 2932, which require that 100 per cent of the stock must be held by Americans or Filipinos. Act No. 3054, an amendatory act passed by the Philippine Legislature in February, 1922, and approved by the President of the United States * May, 1922, provides that citizens of other countries whose laws, customs, or regulations refuse similar privileges to the citizens or corporations of the Philippine Islands or of the United States shall not have any interest whatsoever in any leasehold acquired under any of the provisions of this law.

Miners' licenses for timber must be taken out with the Bureau of Forestry (see p. 542).

Water rights still fall under the operation of the old Spanish law of waters (see p. 543).

TAXES, ROYALTIES, AND RENTALS

All miners' taxes (except for timber licenses) are paid to the Bureau of Internal Revenue according to its rulings and regulations. There is a 1.5 per cent tax on the gross output of metal mines, and an additional wharfage charge, which virtually amounts to an export tax, of 2 pesos on each ton of ore.

All male persons between the ages of 18 and 60 years in the Philippines pay a cedula (poll) tax of 2 pesos annually and all citizens of the United States are subject to the Federal income tax. (Efforts are being made at Washington to have Congress do away with the last-mentioned tax with respect to citizens residing in the Philippines.)

* Under the Jones Law (Act of Congress of August 29, 1916) Philippine legislation referring to "land of the public domain, timber, and mining," is subject to veto by the President. In case he fails to act within six months after receipt of a bill, it automatically becomes a law.

LAW RELATING TO METAL MINES

Lode claims.—In many respects the Philippine law relating to metal mines is like that in effect in the United States, the chief difference being that there are no extra-lateral rights, operations being confined by all side lines extended vertically downward.

Locators are limited to one claim, square in shape, of 300 meters on a side, on each vein or lode.

Persons interested in one mining company are prohibited from having financial interests in any other, although no penalty is provided for disregard of this provision. "Discovery" is necessary to locate a claim.

The procedure with regard to recording, assessment work, etc., is essentially the same as under the United States federal law.

Placer claims.—No placer claim shall contain more than 8 hectares for each individual claimant, and no claim shall exceed 64 hectares for any association of persons, irrespective of the number of persons composing such association.

Patents giving permanent rights to both lode and placer claims may be secured by purchase at any time after improvement work to the amount of 1,000 pesos has been done on each claim. The price of the claim is 25 pesos per hectare.

LAW RELATING TO COAL LANDS

Citizens of the United States or of the Philippine Islands, or corporations the majority of whose stockholders are citizens of the United States or of the Philippine Islands, may take out leases for fifty years on coal lands in the public domain, in blocks of not less than 400 nor more than 1,200 hectares each. No lessee may acquire more than 1,200 hectares.

On lands of private ownership, there is an annual tax of 2,000 pesos on each block of 400 hectares or fraction thereof and a royalty of 4 centavos on each metric ton, which tax is in lieu of all other taxes.

Coal leases are granted according to priority of application. The rental is 2.50 pesos per hectare for the first year and 5 pesos per hectare for each following year, which rentals may, however, be credited against royalties for the same year.

Subleases will be allowed, only in special cases, by the Secretary of the Department of Agriculture and Natural Resources.

A coal operator at present is subject to the following taxes:

	Pesos.
Rental, chargeable against royalties:	
First year (per hectare)	2.50
Second year (per hectare)	5.00
Royalty (per metric ton)	0.10
Specific tax (per metric ton) not less than	0.50

The coal regulations, which were previously very exacting, have been recently revised and made more liberal, particularly those relating to reports, etc.

PETROLEUM LANDS

All public lands containing petroleum or natural gas may be applied for under lease, said leases to cover blocks of 400 hectares for an individual and of 1,200 hectares for an association or corporation. At the discretion of the Secretary of Agriculture and Natural Resources, more than one lease may be granted to any one person, association or corporation.

The exploration and exploitation of deposits on private land shall be under terms and conditions especially prescribed in the regulations, but no operations may be carried on without the consent of the owner. The same royalty is imposed as in the case of public lands, 60 per cent of which royalty goes to the Government and 40 per cent to the private owner.

In all cases the term of a drilling lease is five years and successive renewals are permitted as long as bona fide operations continue, up to fifty years. After fifty years, a new application may be filed in accordance with the rules and regulations. There is no bidding on the application for a petroleum lease.

The rentals are as follows:

For leaseholds within twenty-five (25) kilometers from the coast by the most direct feasible route:

	Pesos per hectare.
First year	0.00
Second year:	
First semester	1.00
Second semester	4.00
Third year	5.00
Fourth year	5.00
Fifth year	5.00

For leaseholds beyond twenty-five (25) kilometers from the coast by the most direct feasible route:

	Pesos per hectare.
First year	0.00
Second year	1.00
Third year	1.00
Fourth year	5.00
Fifth year	5.00

Where the lease is less than 25 kilometers from the coast the lessee has eighteen months in which to start boring. Beyond this limit, three years are allowed. Except during the first year, rentals are collected in each case, until boring operations are commenced.

The royalty is graduated from 8 to 12.5 per cent, depending upon the distance from the coast and the capacity of the wells.

Exclusive geological exploration leases for one-year periods, with a one-year renewal, may be secured on blocks of 400 or 1,200 hectares each in numbers at the discretion of the Secretary of Agriculture and Natural Resources.

MISCELLANEOUS MINERAL PRODUCTS

Stone, guano, clays, etc., are taken out under placer claims according to Act of Congress of July 1, 1902. Special provision for the sale of saline lands is made in section 58 of Act of Congress of July 1, 1902.

TIMBER LICENSES AND TAXES

Miners' licenses must be secured from the Bureau of Forestry. Timber cut within a mining claim will cost the owner nothing; if outside and to be used for mine development, one-half Government charge; that is, 0.25 to 1.25 pesos per cubic meter, depending upon the group to which

the tree belongs. All Philippine forest trees are classified according to first, second, third, and fourth groups (see pages 543 to 549 for discussion of timbers).

WATER RIGHTS AND POWER SITES

All water rights in the Philippines are subject to the Spanish Law of Waters of August 3, 1866, and are administered by the Secretary of Commerce and Communications through the Director of Public Works, according to the provisions of Act of the Philippine Legislature 2152 (as amended by Act 2652).

Priority of appropriation of public waters is as follows: Domestic; agriculture; industrial; ponds and fisheries; mining, milling connected with mining.

Forms for application may be secured from the Director of Public Works, Manila. The standard of measurement of flow of water is the liter per second of time—the unit of volume of hectare-meter. The appropriator of water for power purposes for large development must pay the Government an annual rental of 50 centavos per horse-power for the first ten years; after that at the rate to be determined by the Secretary of the Department of Commerce and Communications.

CORPORATIONS

All corporations must comply with the provisions of The Corporation Law, Act 1459, as amended. Section 6 of this law reads:

"Five or more persons, not exceeding fifteen, a majority of whom are residents of the Philippine Islands, may form a private corporation for any lawful purposes by filing with the Bureau of Commerce and Industry, articles of incorporation duly executed, etc."

Section 68 reads:

"No foreign corporation or corporations formed, organized or existing under any laws other than those of the Philippine Islands, shall be permitted to transact business in the Philippine Islands until after they shall have obtained a license for that purpose from the Director of the Bureau of Commerce and Industry either upon the order of the Secretary of Finance (in case of banks) or upon the order of the Secretary of Commerce and Communications in the case of all other foreign corporations."

Fees graduated according to capitalization are charged for the filing of articles of incorporation, and a foreign corporation must pay similar fees in order to secure a license to do business in the Philippine Islands.

PHILIPPINE FORESTS AND TIMBERS

The lowland areas of the Philippines are generally well forested (Plate 23), especially in the hilly regions, where most of the lode mines are located. The highlands of Luzon are as a rule not so well forested and the chief timber tree is the pine (*Pinus insularis*).

On the summits of the higher peaks, 1,800 to 2,400 meters, there is usually a so-called mossy forest. The highest peaks, above 2,550 meters, are generally bare.

The following notes are from a Bureau of Forestry leaflet:

Area.—The virgin forests of the Philippine Islands cover approximately 103,600 square kilometers, about equal to the area of the State

of Kentucky. This is about one-third of the total area of the Archipelago. In addition there are estimated to be about 51,800 square kilometers of second-growth forest which will yield large quantities of firewood and some small-sized timber. Taken together, the virgin and second-growth forests of the Philippines cover an area about equal to that of the State of New Mexico.

Ownership.—More than 99 per cent of the timber belongs to the Philippine Government and is under the administrative control of the Bureau of Forestry. Less than 1 per cent of the timber is held under sure title of private ownership.

Composition.—About 70 per cent of all Philippine timber belongs to the dipterocarp family (Plate 23), which is generally found in stands which are almost pure from the lumberman's point of view. The largest individuals of this family reach 60.8 meters in height and some specimens have a diameter of 2.13 meters. This family is by far the most important, as it furnishes the main bulk of the timber cut in the Philippines. About a dozen botanically distinct species furnish probably 80 per cent of the entire cut. From the standpoint of the lumberman, however, this number can be reduced to three groups; namely, the lauans, apitongs, and yacals.

Yacals.—This group comprises trees locally known as yacal, narig, mangachapuy, and dalingdingan. The timbers are hard and durable and are more plentiful than the other very durable commercial woods of the Islands.

Apitongs.—The apitong group comprises timbers known as apitong, panao, hagachac, and guijo. The first three are marketed under the name of apitong. Guijo is generally considered somewhat superior. Well-seasoned timbers of this group weigh between 40 and 50 pounds per cubic foot.

Lauans.—It is in this group that the main wealth of the Philippine forest lies. It comprises timbers locally known as white lauan, red lauan, almon, balacbacan, bagtican, mayapis, tiaong, and tanguile. For the sake of simplicity, they may be divided into two classes; namely, white and red lauans. Export grades of the red lauans are used in Europe and America as substitutes for mahogany, and are frequently sold as such. While not so hard and durable as mahogany, lauan has a beautiful grain and admits of a very fine polish.

The main bulk of the forests produces timbers of comparatively few kinds and in some instances approaches pure stands of one or two grades. It is estimated on an average that 70 to 80 per cent of all the dipterocarp forests will yield timbers that belong to the groups described above.

Leguminosæ.—Next in importance to the dipterocarp family are the Leguminosæ, or locust family, to which a number of the commercially important cabinet woods of the Philippines belong. Among the principal representatives of this family are narra, tindalo, ipil, supa, acle, and banuyo. No finer hardwoods are found anywhere in the world.

Stand.—The average stand in the virgin forests of the Philippines may be roughly estimated to run 6,000 board feet per acre and over. On some of the tracts now being worked under long-term license agreements (or concessions as they are popularly called) the stands run between 15,000 and 35,000 board feet per acre. Stands of 45,000 to 60,000 board feet

per acre are not infrequent, principally at elevations between 800 and 1,200 feet above sea level.

Obtaining a tract of timber.—The public forests of the Philippines are not sold, but are developed under a license system. Small operators usually work under ordinary yearly licenses for definite small areas. Exclusive licenses, or concessions as they are popularly called, are generally in the form of twenty-year exclusive license to cut and extract timber and other forest products from a specified tract. The land itself is in no way affected by such a license as merely the timber and minor forest products are included.

FOREST CONDITIONS IN AROROY DISTRICT, MASBATE *

Timbers are necessary for two general classes of construction; namely, temporary and permanent. Many temporary tunnels are run in the development of the mines. These can be timbered with the cheaper woods, among which are lauan and toog. If such tunnels prove to be permanent, the timbers can be replaced. Of course molave is the most durable, and it could be used for footings and posts. The supply of molave is limited, however, and unless it is utilized with the greatest care, it will soon be exhausted. The same can be said for the other first and second-group timbers, such as narra, tindalo, and dungon. As a rule, these timbers should be saved for the most permanent structures, as posts for mills and other buildings and special places in tunnels. Tamayuan appears to be more durable than any of the other cheaper-grade timbers, but if used exclusively for props, etc., the most accessible supply will soon be exhausted. Little or nothing is known of the comparative durabililty of the remaining timbers. Two of the most promising of these are toog and dao. Magalipac, marobo, and lauan are much softer and probably much less durable. There is no doubt that all of these timbers are far less durable than the well-known first- and second-group woods. Experience alone will tell which are most suitable. Amuguis, guijo, and apitong are of a better grade, but are limited in amount.

TIMBER TREES

TOOG, *Terminalia quadrialata* Merr.

The tree has a regular unbuttressed bole, which reaches from 80 to 120 centimeters in diameter, and runs from 20 to 30 meters in length. It is a constant associate of lauan in the lower-slope type. Here, according to estimates based on 6.5 hectares, it averages twelve trees over 30 centimeters in diameter per hectare. In the ridge type, there are seven trees per hectare, though it is entirely absent on the most-exposed situations. The reproduction of toog is not good. Few seedlings are present, and a count of 4 hectares shows only about half as many poles per hectare as trees.

* Extracts from a paper by H. N. Whitford, formerly forester in the Bureau of Forestry; originally published in Mineral Resources of the Philippine Islands for the year 1909 (1910) 72–78. Aroroy, Masbate, is one of the chief gold-mining districts to-day in the Philippine Islands, and this will serve for other lowland districts.

The bark of toog is 10 to 12 millimeters in thickness. The outer bark is dark red, nearly black when wet, and has irregular lines of prominent, corky pustules. It is scalloped with irregular depressions as large as saucers, which mark the places of recent shedding. The inner bark is tan-red and very stringy. The proportion of sap to heartwood is about 1 to 4. The heartwood is a dull dark red, resembling somewhat the color of the wood of dungon. The wood is said to be fairly durable.

LAUAN, *Parashorea plicata* Brandis.

The bark has flat-topped, long or short, anastomosing ridges. It is 10 to 15 millimeters in thickness, and is brown in color. Just beneath the outer bark there is usually a thin, purplish layer. The inner bark has alternating vertical tan-red and white bands, the latter being located beneath the depression. The sapwood is a creamy yellow; the heartwood is brown to slightly pinkish in color.

The lauan of Masbate has a straight, regular bole. It is decidedly the most abundant species of the region, and occurs in pure stands. If it could be utilized, it would be the most valuable tree in the district. As already stated it is found in the lower-slope type, and will thrive on ridges where the soil is sufficiently deep. The reproduction is excellent. Seedlings, saplings, and poles are the principal features of the undergrowth in many portions of the lower-slope type.

TAMAYUAN, *Strombosia philippinensis* Rolfe.

This tree is found distributed through the lower-slope type. It forms a conspicuous part of the undergrowth of the lower-slope type. It is a tree that seldom reaches a diameter of 40 centimeters when mature.

The bark is 5 to 12 millimeters thick. The outer bark is smooth, dark brown, nearly black, and is covered with lines of corky pustules. This is shed in large irregular plates, and the new bark thus exposed is cinnamon-brown. The inner bark is yellow, with white concentric bands. The bole is usually slightly irregular.

The wood is hard and probably durable, although there is as yet little reliable information concerning its durability. The sapwood has a very slight reddish or purplish tint, which becomes more pronounced in the heartwood. The line between the heartwood and the sapwood is very irregular; sometimes forks of the former extend into the latter. This wood is one of the most promising of the mining timbers. It is used almost exclusively by one company for props and footings.

DUNGON, *Tarrietia sylvatica* Merr.

This tree is distinctly of the ridge type, where it reaches its best development, although here it averages only twenty-eight trees per hectare. The bark of dungon is 8 to 10 millimeters thick. The outer bark is cinnamon brown, ashy gray, and is covered with corky pustules. It looks much like guijo. It is shed in large scroll-like patterns. The inner bark has a delicate pink-tan color with fine concentric lines. The proportion of sapwood to heartwood is about 1 to 4. The former is white, lightly tinged with red, and the latter is a very dark brownish red. The tree has an irregular bole and is sometimes strongly buttressed. The largest tree noted had a diameter of about 80 centimeters and a clear

length of at least 15 meters. The reproduction of dungon is fairly good. Seedlings, saplings, and poles form a proportional share of the undergrowth near the mature trees. The tree, while intolerant, is slightly less so than its associates, molave and tindalo.

Dungon is one of the most durable timbers of the region, but because of its limited quantity should be used sparingly.

TINDALO, *Pahudia rhomboidea* Prain.

Tindalo is distinctly a ridge-type tree, but even here it is very scattered, forming only 15 trees per hectare.

The bark of tindalo is about 10 millimeters thick. The outer bark is creamy yellow, is uneven on the surface, and is covered with corky pustules. This uneven surface is due to the saucerlike depressions left when the bark is shed. The inner bark is brownish yellow.

The reproduction of tindalo is poor. All trees noted were mature or nearly mature.

MOLAVE, *Vitex parviflora* Juss.

Molave belongs distinctly to the ridge type of forest, where, according to the estimates made, it averages 2.4 trees per acre.

The bark of molave is 8 to 10 millimeters thick. The outer bark is a light yellow-brown, and has a smooth, slightly shreddy, but uneven surface. The inner bark is light yellowish with darker yellowish concentric rings. It quickly turns brown on exposure. The bole of the tree is very irregular and often shows a spirally twisted trunk.

The reproduction of molave is exceedingly poor; although a constant search was made for seedlings, none were found. Indeed, the smallest tree noted was 20 centimeters in diameter, although many of the trees were in flower or fruit. The tree is exceedingly intolerant of shade, and consequently occupies the most open places. It is more abundant on the border of grassland than elsewhere. Colonies of trees, gnarled and stunted in growth, are often found isolated on rocky ridges in the cogonales themselves. That the tree does not occupy the drier ridges from choice is evidenced by the fact that occasional trees were noted in open places in the lower slope, and even in the river-bottom types. Especially is this true along the border of the narrow strips of forest in the cogonales that skirt the streams. The appearance of molave on the dioritic rocks of this region shows conclusively that it is not confined to limestone rocks, as is commonly believed.

Molave is the most abundant and most durable of the woods of the region. Many of the trees, though old and decayed, contain a sufficient amount of sound wood for construction purposes. As the tree is failing to reproduce, no future crop is growing up.

GUIJO, *Shorea guiso* Blume.

Guijo is found in very limited quantities in the lower-slope type. The bark is 7 millimeters thick; the outer bark is cinnamon-brown where freshly shed, and thickly set with corky pustules. The darker, older bark breaks in vertical flakes. The inner bark is brown-tan to cream color tinged with tan. The trunk is straight, cylindrical, and clear of defects.

NARRA, *Pterocarpus indicus* Willd.

Narra, although most abundant in the river-bottom type, is not confined entirely to that, for the lower-slope type shows 1.5 trees per hectare, and even on the dry ridges there are scattering trees.

The bark of narra is 3 to 5 millimeters in thickness, the outer bark is brown to olive-gray, soft, and minutely flaky. The inner bark is light red, streaked with darker red, short tubes, united in vertical rows. These tubes, on being cut, exude a dark red sap which, on solidification, becomes very reddish brown. Narra is not quite so intolerant of shade as molave. So far as tolerance is concerned the ridge type would be an ideal place for it, but here the soil conditions are probably too dry at certain seasons of the year. If it were more tolerant, the lower-slope type would be the ideal place for it, as evidenced by the fact that it here reaches its best development. It is, however, usually crowded to the borders of streams where, besides a sufficient supply of moisture, it has better light conditions than can be obtained in the close forests of the lower-slope type. The reproduction of narra is fairly good. In open places, near seed trees, many seedlings are often present; away from these there are scarcely any.

Narra is a durable wood in contact with the ground, but because of its limited supply and its high value for cabinet wood, it should be used sparingly for construction work.

AMUGUIS, *Koordersiodendron pinnatum* Merr.

Amuguis follows narra in its distribution, being most abundant in the river-bottom type, less so on the lower-slope type, and almost entirely wanting in the ridge type. It is a good general construction timber where it is not in contact with the soil. It is, however, probably much more durable in contact with the soil than many of the fourth-group timbers.

DAO, *Dracontomelum dao* (Bl.) Merr. and Rolfe.

Dao is one of the most promising of the little-used or unused timbers. The tree is constantly associated with narra and amuguis in the river-bottom type, to which type it is almost entirely restricted.

HAGACHAC or APITONG, *Dipterocarpus affinis* Brandis.

This tree, known locally as apitong, is almost entirely restricted to the river-bottom type. Here it occurs in pure stands which are extremely limited in area, because the physiographic type in which it grows is so limited. Hagachac can be readily distinguished from true apitong (*Dipterocarpus grandiflorus*) by the fact that it has hairy leaves, whereas the leaves and petioles of apitong are smooth. There is little doubt that hagachac is as good a constructive timber as apitong. It, like apitong, is not considered durable in contact with the ground, but is probably more so than any of the fourth-group timbers herein mentioned.

MAGALIPAC, *Sterculia blancoi* Rolfe.

This is a timber that occupies first place in abundance in the ridge type, and is third in the lower-slope type. It is a timber that is as soft as or softer than lauan, and is probably not durable.

MAROBO, *Diplodiscus paniculatus* Turcz.

Marobo is a little-known timber that occupies fourth place in abundance in the ridge type. Nothing is known about its durability.

Other timbers that deserve mention are malaguibuyo (*Celtis* sp.), cubi (*Artocarpus* sp.), matobato (*Trewia ambigua* Merr.), magatalisay (*Terminalia nitens* Presl), calamansanay (*Nauclea* sp.), and *Kingiodendron alternifolium* (Elm.) Merr.

Little or nothing is known of malaguibuyo. It is closely related to a species known as malaicmo. It is not durable. Cubi is identical with or closely related to the anubing of commerce. It is known to be durable in contact with the ground. While only two trees were noted, a more careful search might show that there are localities where it is more abundant. Magatalisay is the sacat of commerce and is valuable for light construction purposes. Matobato is said to be fairly durable, and is ranked with tamayuan. It is little used, however, probably because it is not abundant. Batete is another wood the qualities of durability of which are little or not at all known. It forms almost pure stands in some portions of Masbate; it is used locally for floors and siding in house construction.

THE MANGROVE SWAMPS

On the east side of Barrera Bay there are two areas of mangrove swamps (mangles), occupying in all some 10 square kilometers. These lie at the mouths of Guinobatan and Lanang Rivers. The latter is most extensive, and except for narrow strips along both margins of the river, has been little utilized. The woods of these swamps are most valuable for firewood.

Since Whitford wrote the article from which the above notes are taken, the swamps of mangrove near the mines in Masbate have been pretty well cut over, and the supply of this particular class of timber is maintained by bringing it in sailboats from the swamps along Ragay Gulf, over 50 kilometers distant. This timber is used in the mine and not as fuel in this district. In the Paracale district in the dredging field it was and still is to a limited extent used chiefly for fuel on the dredges.

"Oregon pine," which is not pine but Douglas fir, has been used much in mill construction in the Philippines but this is not usually recommended.

The two chief destructive agents of timbers that the mine foreman has to consider are white ants, or termites, and fungi. The former are not abundant in temperate regions, and the latter are more devastating in the Tropics because of the continuous heat and high moisture. Mine timbers in the Philippines will either have to be treated with preservatives or be continually renewed.

MINERAL LANDS AND MINE OPERATORS

MINERAL LANDS SEGREGATED FROM THE PUBLIC DOMAIN

1. Patents issued under Act of Congress of July 1, 1902. The patents issued under this Act from July 1, 1902 to December 31, 1920 are as follows:

Lode patents.

Year.	Claims.	Area.
		Hectares.
1908	5	36.3020
1909	32	264.5927
1910	15	127.1274
1911	1	5.0447
1912	2	17.6568
1913	9	70.7067
1916	7	61.1829
1917	2	4.4670
1918	2	18.0000
1919	9	54.5652
1920	11	81.2551
Total	95	740.9005

Placer patents.

Year.	Claims.	Area.
		Hectares.
1908	1	5.5887
1909	6	40.0960
1911	1	6.9138
1912	2	50.3156
1913	2	56.4430
1914	2	25.0255
Total	14	184.3826

2. Patents issued under Act 1128. The patents issued under this Act are as follows:

Year.	Claims.	Area.
		Hectares.
1905	1	34.0000
1907	2	128.0000
1909	3	48.0000
1911	1	64.0000
1917	1	64.0000
1918	3	48.0000
Total	11	386.0000

3. Operations under Act 2719. The permits and leases under this Act are as follows:

Coal revocable permits.

Year.	Claims.	Area.
		Hectares.
1918	13	46.0000
1919	22	82.0000
1920	26	99.0000
Total	61	227.0000

Coal leases.

Year.	Claims.	Area.
		Hectares.
1918	2	1,512.0000
1920	1	400.0000
Total	3	1,912.0000

4. Operations under Act 2932. This Act was recently enacted by the Philippine Legislature and under it for the period to 1920, only three leases, comprising 3,600 hectares, have been granted.

5. Summary of operations under various Acts:

	Claims.	Area.
		Hectares.
Act of Congress:		
Lodes	95	740.9005
Placers	14	184.3826
Act 1128	11	386.0000
Act 2719:		
Coal revocable permits	61	227.0000
Coal leases	3	1,912.0000
Act 2932	3	3,600.0000
Total	187	7,050.2831

Directory of mine operators in the Philippine Islands.

GOLD.

Name.	Post-office address.	Location of mine or property.	Activity.
Acupan Mining and Milling Co	c/o Wm. M. Haube, 827 R. Hidalgo, Manila	Batwaan Creek, Benguet, Luzon	Developing.
Antamok Valley Mining Association	c/o Wolfson and Wolfson, 65 Plaza Cervantes, Manila.	Antamok Valley, Benguet, Luzon	Do.
Argus Mining Co	Napuangan, Aroroy, Masbate	Napuangan, Aroroy, Masbate	Do.
Benguet Consolidated Mining Co	Kneedler Building, Manila	Antamok, Benguet, Luzon	Milling.
Demonstration, Ltd	c/o H. P. Whitmarsh, Baguio, Mountain Province.	Tuba, Benguet, Luzon	Developing.
Gillies, John S	Suyoc, Mountain Province	Suyoc, Lepanto, Luzon	Small-scale operations.
Headwaters Mining Co	Baguio, Mountain Province	Antamok River, Benguet, Luzon	Developing.
Itogon Group	c/o I. B. Dexter, Manila	Itogon, Benguet, Luzon	Do.
Kuruon Mining Co	Zamboanga, Mindanao	Zamboanga, Mindanao	Do.
Magma Group	c/o H. P. Whitmarsh, Baguio, Mountain Province.	Itogon, Dunglan Creek, Benguet, Luzon	Do.
Mentzer, George	Binalonan, Pangasinan	Lubang, Mountain Province	Milling, small scale.
Lianga Mines, Ltd	Lianga, Mindanao	Lianga, Mindanao	1 dredge operating.
Philippine Dredges, Ltd	Paracale, Ambos Camarines	Paracale River, Camarines Norte, Luzon	2 dredges operating.
Schwab, Paul	Aroroy, Masbate	Aroroy, Masbate	Intermittent operations.
Syndicate Mining Co	101 Lara, Manila	do	Milling.
Tiago Group	Aroroy, Masbate	Cabuyudu River, Aroroy, Masbate	Developing.
Inca Group	Baguio, Mountain Province, c/o Wm. Ebert	Antamok River, Benguet, Luzon	Do.

IRON.

Concha, Francisco de la	Sibul Springs, Bulacan	Sapang-bacal, San Miguel, Bulacan	Operating.
Concha, Joaquin de la	Cabanatuan, Nueva Ecija	Camaching, San Miguel, Bulacan	Do.
Cruz, Anacleto	Angat, Bulacan	Muntamurong, Angat, Bulacan	Do.
Fernando, Juana A	do	Maon and Macabaroc, Angat, Bulacan	Do.
Fernando, Maria A	do	Sapang-bacal, Angat, Bulacan	Do.
Fernando, Matias A	do	Angat, Bulacan	Do.
Fernando, Valentin A	do	do	Do.
Sarmiento, Marto	Angat, Bulacan	Sapang Caliñgog, Angat, Bulacan	Operating.
Sarmiento, Vicente	do	Sampaloc, Angat, Bulacan	Do.

COPPER.

Mancayan Copper Mines	Mankayan, Lepanto, Mountain Province	Mankayan, Mountain Province	Developing.

LEAD, ZINC, AND COPPER.

Marinduque Mining Co	c/o E. E. Elser, Kneedler Building, Manila	Marinduque Island	Idle.
Schwab, Paul	Aroroy, Masbate	Masbate Island	Developing.

ASBESTOS.

Ilocos Asbestos Products Co	Manila	Dungon-Dungon, Bangui, Ilocos Norte	Idle.

ASPHALT AND BITUMINOUS LIMESTONE.

Leyte Asphalt and Mineral Oil Co., Ltd	Villaba, Leyte	Villaba, San Isidro and Leyte, Leyte	Developing.

Directory of mine operators in the Philippine Islands—Continued.

COAL (PRODUCERS ONLY).

Name.	Post-office address.	Location of mine or property.	Activity.
Abella, Apolinar	Cebu, Cebu	Lotloton, Toledo, Cebu	Revocable permit.
Adlawan, Monico	Talisay, Cebu	Pooa, Toledo, Cebu	Do.
Alecaba, Pablo	Toledo, Cebu	Near Toledo, Cebu	Do.
Alferes, Placido	----do	Masaba, Cantabaco, Toledo, Cebu	Do.
Ariate, Juan	----do	Near Toledo, Cebu	Do.
Bajarias, Fausta	Dalaguete, Cebu	Mantalongon, Dalaguete, Cebu	Do.
Barker, F. E	Legaspi, Albay	Carcaran, Batan	Do.
Bellesa, Luis G	Naga, Cebu	Naga, Cebu (?)	Do.
Buntayan, Gregorio	Cebu, Cebu	Near Toledo, Cebu	Do.
Canonigo, Vicente	Naga, Cebu	Naga, Cebu (?)	Lease.
Cepado, Restituto	Minglanilla, Cebu	Minglanilla, Cebu	Revocable permit.
Codilla, Aquilina	128 Colon, Cebu, Cebu	Near Toledo, Cebu	Do.
Cumings, Edgar G	Toledo, Cebu	Cambanog, Toledo, Cebu	Do.
Danao Coal Mining Syndicate, Ltd	Danao, Cebu	Danao, Cebu	Private.
Enriquez, Eugenio	1 Manila St., Cebu, Cebu	Guinkiyutan, Toledo, Cebu	Revocable permit.
Ford Lease	c/o C. D. Johnston, Cebu, Cebu	Naga, Cebu	Lease.
Iriarte, Prudencio	100 Juan Luna, Cebu, Cebu	Cantabaco, Toledo, Cebu	Revocable permit.
Jara, Arcadio	Capilihan, Cebu	Capilihan, Cebu	Do.
Jola, Arcadio	Talisay, Cebu	Talisay, Cebu	Do.
Juarez, Antonia	----do	Cabungahan, Cebu	Do.
Lebomfacil, Lorenzo	Toledo, Cebu	Masaba, Cantabaco, Toledo, Cebu	Do.
Libre, Teofilo	Cebu, Cebu	Near Toledo, Cebu	Do.
Natad, Ambrosio	----do	----do	Do.
National Coal Company:			
Cebu	----do	Mount Licos, Cebu	Government
Mindanao	Malangas, Mindanao	(1) Gotas, (2) Butong, (3) Camp Wilmot, Mindanao.	Do.
Philippine Coal Mining Co	Box 752, Manila	Batan, Batan Island	Lease.

Rivera, Benito and Rivera, Teofilo	Naga, Cebu	Cantabaco, Naga, Cebu	Revocable permit.
Saysen, Isidro	do	Naga, Cebu	Do.
Toledo Coal Mines, Ltd	Box 494, Manila	Taop, Toledo, Cebu	Lease.
Uling Coal Mines, Ltd	Cebu, Cebu	Uling, Naga, Cebu	Private.
Veloso, Moises	Naga, Cebu	Naga, Cebu	Revocable permit.
Villaver, Alberto	Tubod, Minglanilla, Cebu	Biga, Toledo, Cebu	Do.
Yriarte, Angel and Yriarte, Prudencio	100 Juan Luna, Cebu, Cebu	Near Toledo, Cebu	Do.

MARBLE (ORNAMENTAL).

Bagondol, Pedro	Romblon, Romblon	Romblon, Romblon	Intermittent operations.
Magdato, Sancho	do	Soypo, Romblon, Romblon	Do.
Magdato, Vicente	do	do	Do.
Martinez, Manuel	do	do	Do.
Mazo, Lope	do	do	Do.
Mindo, Ambrosio	do	do	Do.
Montojo, Rafael	do	Cajimos, Romblon, Romblon	Do.
Moral, Julio	do	Soypo, Romblon, Romblon	Do.
Mula, Roman	do	Romblon, Romblon	Do.

MINERAL WATERS.

Isuan, Inc	Manila	Los Baños, Laguna	Operating.
Corporacion Marilao	Marilao, Bulacan	Marilao, Bulacan, P. I	Do.

Directory of mine operators in the Philippine Islands—Continued.

PETROLEUM APPLICANTS.

Name.	Post-office address.	Location of mine or property.	Activity.
American Oil Co		Tayabas Province	Lease.
Columbia Oil Co		do	Do.
Heise, E. A	Manila	do	Do.
Lucena Oil Co	Lucena, Tayabas	do	Do.
McDaniel, E. W	Manila	do	Prospecting.
Manila Oil and Pipeline Association	do	do	Lease.
Paco Oil Co		do	Do.
Philippine Oil Co		do	Do.
Richmond Petroleum Co	320 Masonic Temple Building, Manila	do	Drilling.
Tayabas Oil Land Association		do	Lease.
Union Oil Co	513 Chaco Building, Manila	do	Prospecting.
Visayan Petroleum Co	Cebu, Cebu	Cebu Province	Lease.
Barclay Petroleum Co		Cotabato Province	Do.
Mindanao Petroleum Co	Zamboanga, Mindanao	do	Do.
Round Mountain Petroleum Co		do	Do.
Anderson, William (association of persons)	c/o Leyte Asphalt and Mineral Oil Co	Leyte Province	Do.
Banisilan Oil Company	Manila	Leyte and Tayabas Provinces	Lease.
SULPHUR.			
Alunan, Gerardo	Silay, Occidental Negros	Silay, Occidental Negros	No production.
Los Valientes	do	do	Do.

MINING COSTS

In order to place at the disposal of persons far from this field the most reliable data concerning mining costs in the Philippines, the following figures have been secured from the Benguet Consolidated Mining Company, the largest and most successful gold property in the Islands. Mr. A. W. Beam, president of the company, who kindly furnished the figures, says that no charge covering interest on capital invested nor any depreciation of machinery, buildings, etc., is included; nor does the power cost include any similar charge on its investment.

It will be noted also that these figures cover a period of exceptionally high prices everywhere. Those for 1921 already show a marked decrease. Figures for years previous to 1918 are not given as they would not furnish so good an index as do those later, for the simple reason that the property was not on as sound a basis as it is now. This mine, it will be recalled, was in operation previous to 1909, when it was completely wrecked in a typhoon, and was not rehabilitated until 1915.

Benguet Consolidated mining and milling costs.

	1918	1919	1920	1921 [a]
Tons treated	23,539	23,719	35,565	18,890
	Pesos.	*Pesos.*	*Pesos.*	*Pesos.*
Mining	5.620	6.191	5.028	3.512
Milling	6.270	8.020	6.401	6 737
Insurance	----------	0.114	0.125	0.152
Taxes, mine products, timber, etc	0.491	0.815	0.679	0.889
Marketing and Manila, general	1.004	1.452	1.655	1.233
Hospital and school	----------	0.172	0.240	0.245
Development and exploration	0.780	0.043	0.581	1.003
Total per ton operation cost	14.165	16.807	14.709	13.771
Power cost per kilowatt hour	0.01935	0.0584	0.0218	0.0266
Mining:				
Superintendence	0.130	0.203	0 265	0.323
Breaking and filling	2.340	3.163	1.946	1.141
Tramming and hoisting	0.530	0.701	0.381	0.434
Timbering	1.430	1.355	1.440	0.757
Miscellaneous repairs	0.260	------	0.319	0.208
Assaying and engineering	0.070	0.092	0.148	0.106
Lighting	0.060	0.116	0.046	0.054
Proportion of camp and mine general expense	0.800	0.561	0.483	0.489
Total	5.620	6.191	5.028	3.512

[a] First half.

Benguet Consolidated mining and milling costs—Continued.

	1918	1919	1920	1921 [a]
Milling:				
Superintendence		0.202	0 291	0.334
Crushing and screening	0.180	0.247	0.232	0.296
Stamping	0.640	0.687	0.528	0.439
Tube milling	1 040	1.694	1.064	1.163
Thickening and agitating	0.520	0.806	0.405	0.552
Precipitating	0.550	0.548	0.349	0.287
Solution	1.210	1.568	1.442	1.350
Refining	0.540	0.498	0.536	0.416
Filtering			0.109	0 190
Miscellaneous repairs and renewals	0 560	0.560	0 538	0.361
Lubricating		0.081	0.063	0.079
Assaying and engineering	0.180	0.336	0.197	0.237
Lighting	0.050	0.076	0.035	0.051
Proportion of camp and mine general expense	0.800	0 717	0.612	0.982
Total	6 270	8.020	6.401	6 737

[a] First half.

Benguet Consolidated mining supplies cost comparisons.

	1918	1919	1920	1921 [a]
Timber	0.870	0.790	0 919	0.422
Lumber and nails	0.170	0.264	0.198	0 385
Explosives	0.180	0 180	0.197	0 138
Candles	0 160	0.188	0.125	0.104
Cars and track supplies	0 070	0 137	0.035	0.064
Shoes-dies-liners	0.120	0.131	0.130	0.090
Tube-mill liners	0.250	0.266	0 260	0.232
Pipe and fittings	0.100	0.053	0.039	0 185
Screens, batteries, and washers		0.017	0 008	0.012
Belting and lacing	0.130	0.060	0.125	0.117
Oil, waste, etc	0.040	0.080	0.063	0 079
Machinery renewals	0.170	0.206	0.262	0.559
Mine tools	0.090	0.090	0.087	0.059
Mill tools	0.040	0.022	0.021	0 043
Cyanide and lime	0.990	1.162	1.233	1.111
Zinc and lead acetate	0.370	0.412	0.273	0.196
Pebbles	0.270	0.407	0.320	0.370
Fluxes and crucibles	0.240	0.140	0.230	0.178
Fuel	0.150	0.431	0.144	0.142
Acids	0.030	0.075	0 068	0.034
Electrical supplies	0.030	0.136	0.098	0.129
Miscellaneous	0.420	0.549	0.404	0·450
Total	4.890	5.796	5.240	5.099

[a] Six months to June 30.

GLOSSARY OF PHILIPPINE MINING TERMS *

APOG, lime; Tagalog.
ASUPRE, sulphur; adopted from Spanish.
BACAL SIGAY, quartzose ore.
BAGON or BAGOL, mine car; Tagalog.
BAKAL, iron; Tagalog.
BALITOK, gold; Ilocano, Pangasinan, Igorot.
BATEA or PABERIK, round gold pan; Camarines Norte.
BATO, stone or rock; Tagalog.
BATONG BUGA, quartz-sandstone.
BRAGANANTES, mold men; adopted from Spanish.
BUMBUNG, tuyure; Bulacan.
DANUM, water; Igorot, Pampango, Pangasinan, Ilocano.
DRAGA, dredge; adopted from Spanish.
ENCARGADO, administrative superintendent; adopted from Spanish.
ESCORIADORES, slag men; adopted from Spanish.
GALERIA, tunnel; adopted from Spanish.
GAMBANG, copper; Igorot.
GAS or PETROLLO, oil, or petroleum, or kerosene; adopted from Spanish.
GUDNA, gold-bearing rock; Ilocano, Igorot.
GUINTO, gold; Tagalog.
HORMAS, molds; adopted from Spanish.
HUNGKUY, blower; Bulacan.
HURNO, furnace; Bulacan.
IG, water; Maguindanao or Manobo Moro.
ISMAY, lead or zinc; Igorot.
JILADORES, blower men; adopted from Spanish.
KAHOY, timber; in general use.
LIPIA, plowshares; Tagalog.
MAESTRO, technical superintendent; adopted from Spanish.
MINA, mine or smelter; adopted from Spanish.
PARES, pairs; adopted from Spanish.
PATNAUAN, table for concentrating fine gold; Pangasinan and Camarines Norte.
PILAK, silver; Tagalog.
POSO, shaft; adopted from Spanish.
SABAK, Igorot gold pan; Igorot.
SUDSUD, plowpoints; Tagalog.
TAENG BAKAL, iron slag; Bulacan.
TANSO, copper; Tagalog.
TIBAGAN, quarry or mine; Bulacan.
TINGA, lead; Tagalog.
TUBIG, water; Tagalog.
TUMBAGA, copper gold alloy; Tagalog.
ULING, charcoal; Tagalog.
ULING BATO or CARBON, coal; Tagalog.
USOK, tunnel; Igorot.
VETA, vein; adopted from Spanish.
WATO, stone or rock; Maguindanao or Manobo Moro.

* The Glossary was compiled by L. A. Faustino.



PLATE 1. SHALES AND AGGLOMERATE IN SUQUI CREEK, CEBU.

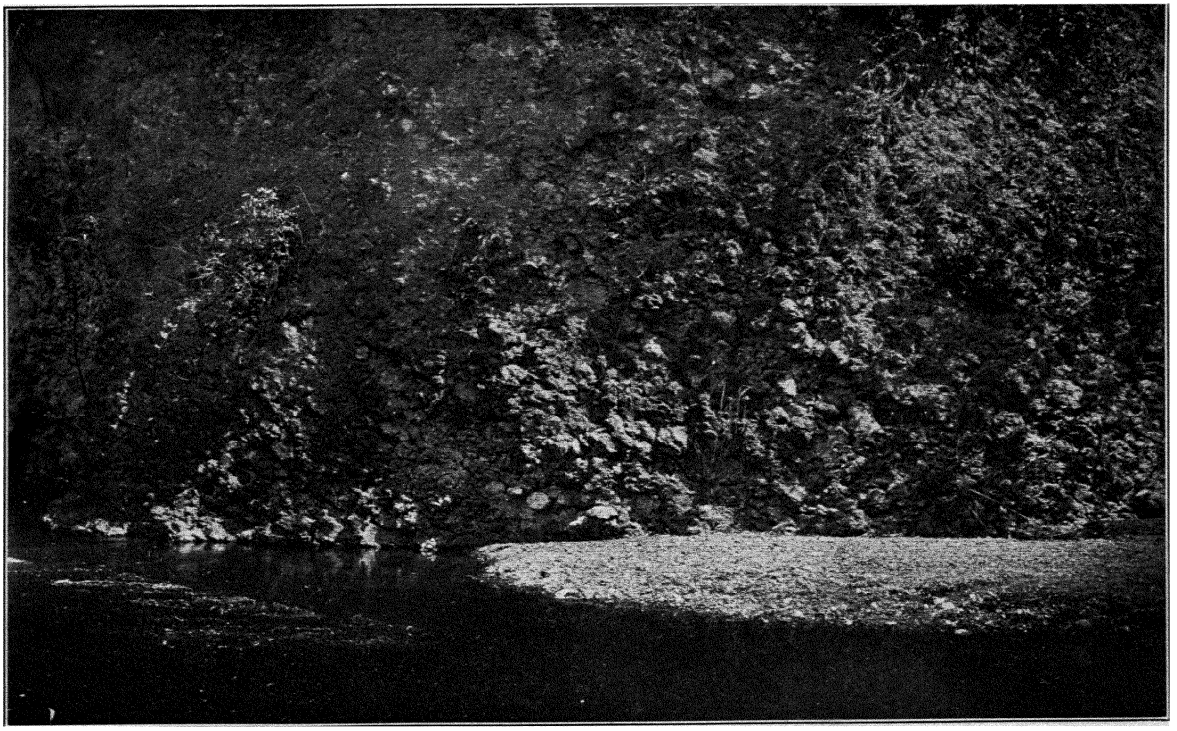


PLATE 2. RUBBLE PLIOCENE (?) LIMESTONE EXPOSED IN A GORGE OF DANAO RIVER, CEBU.

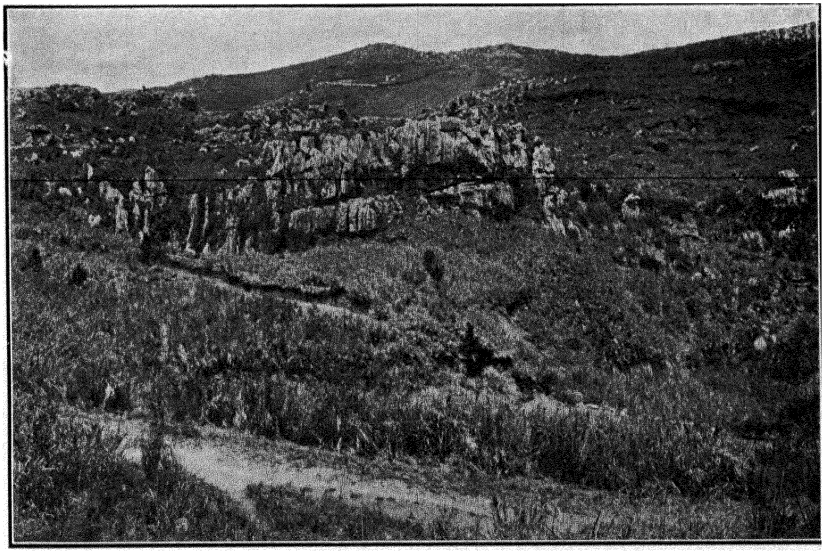


Fig. 1. Malumbang limestone cliffs.

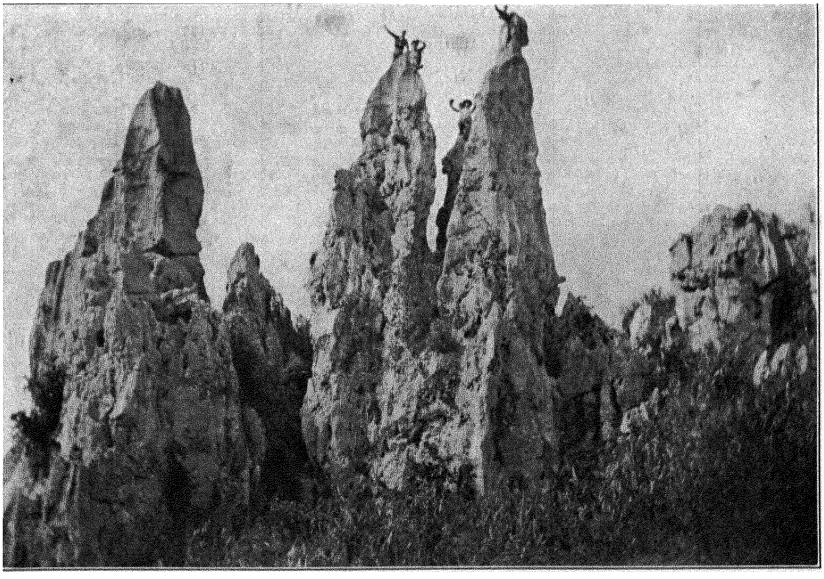


Fig. 2. Limestone needles.

PLATE 3. LIMESTONE AT SAGADA.

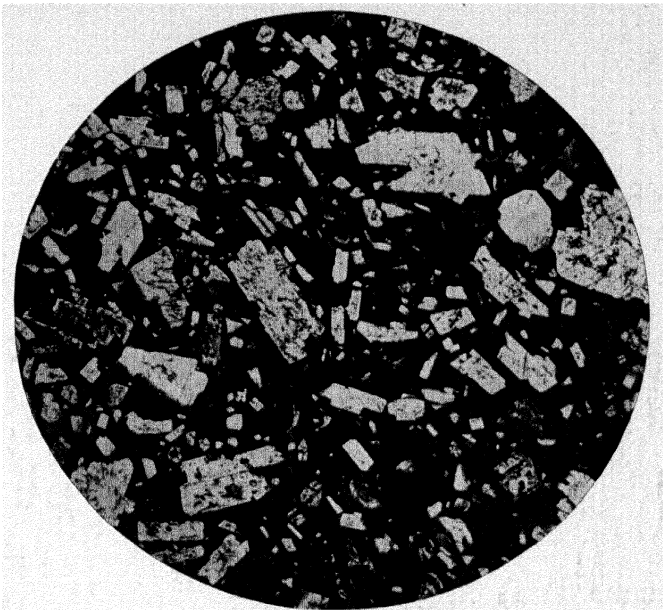


Fig. 1. Hypersthene-augite andesite.

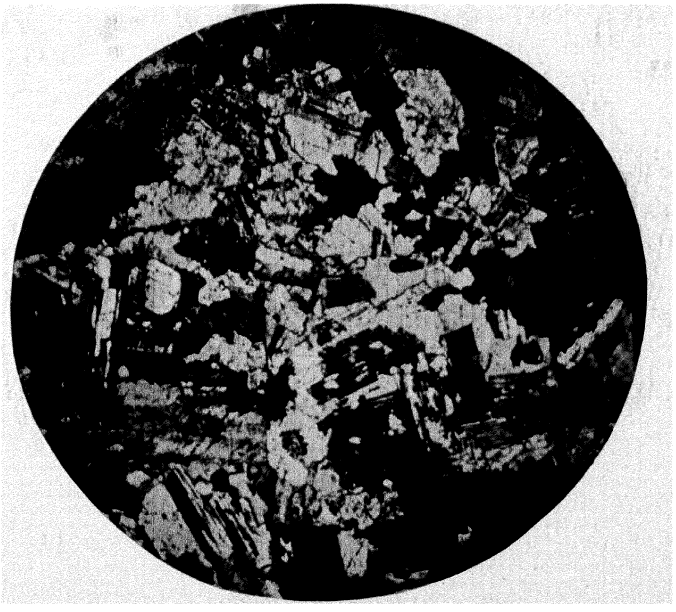


Fig 2. Quartz diorite.

PLATE 4. THIN SECTIONS OF ROCKS FROM BAGUIO.

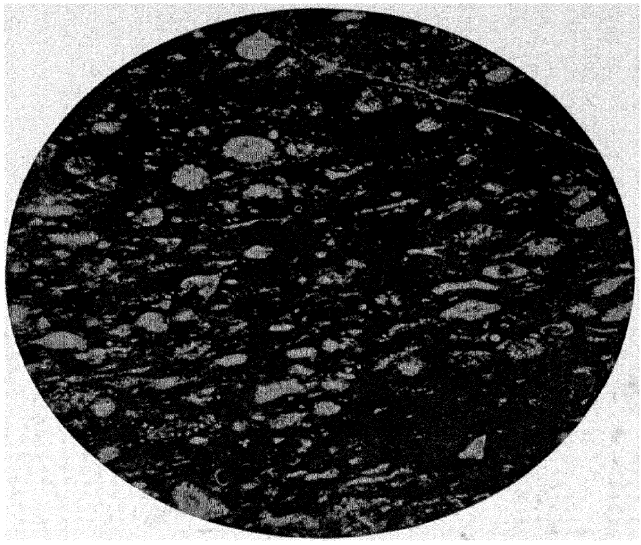


Fig. 1. Thin section of old "slate."

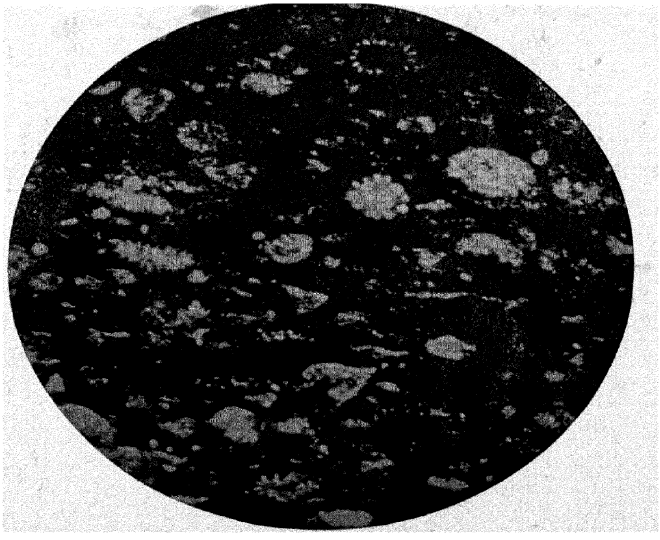


Fig. 2. Portion of the above section enlarged.

PLATE 5. JURASSIC (?) RADIOLARIA.

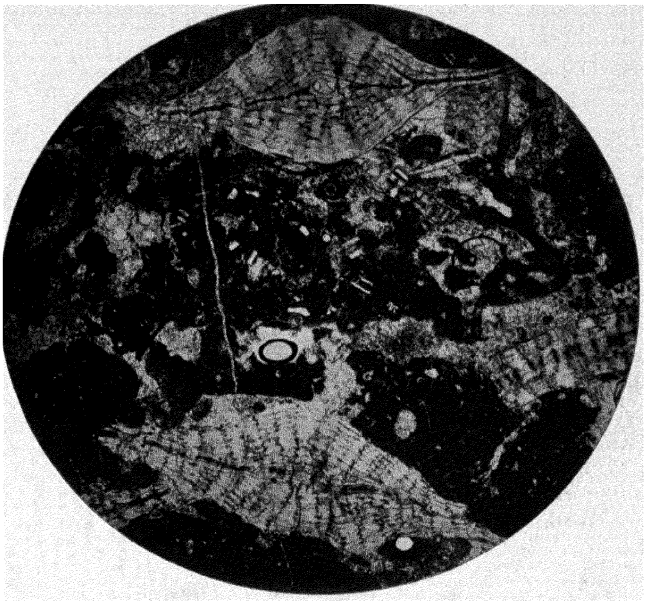


Fig. 1. Orbitoidal limestone from Cebu, showing Lepidocyclina.

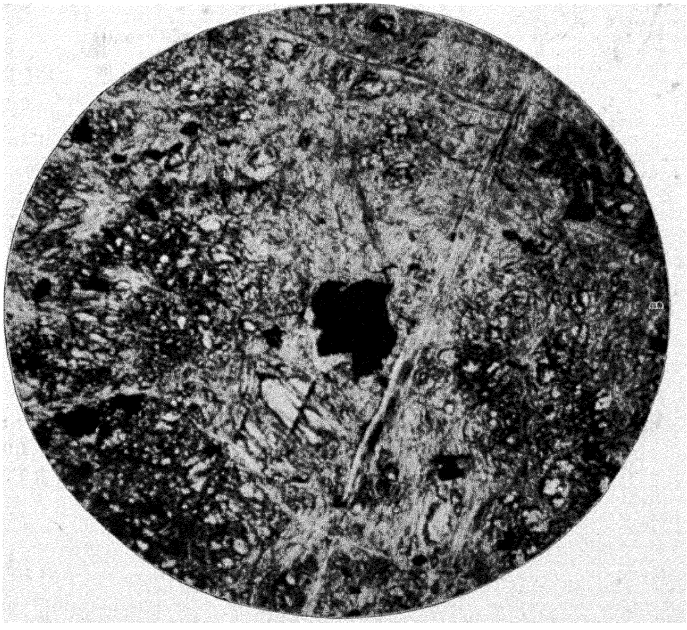
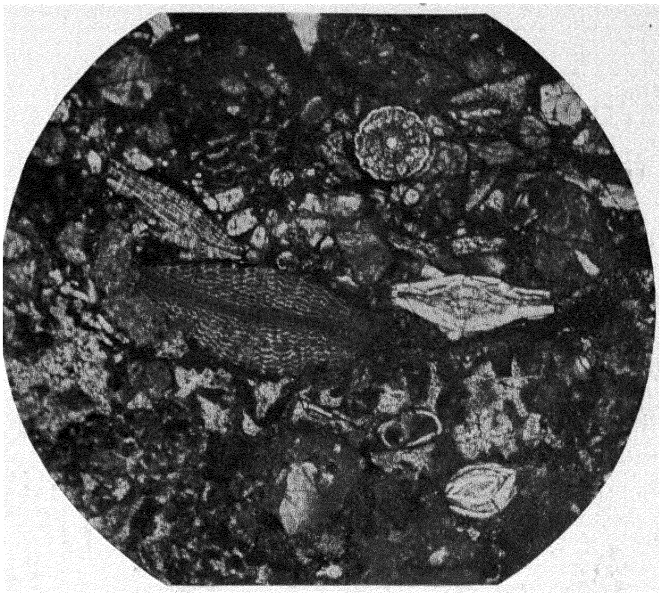
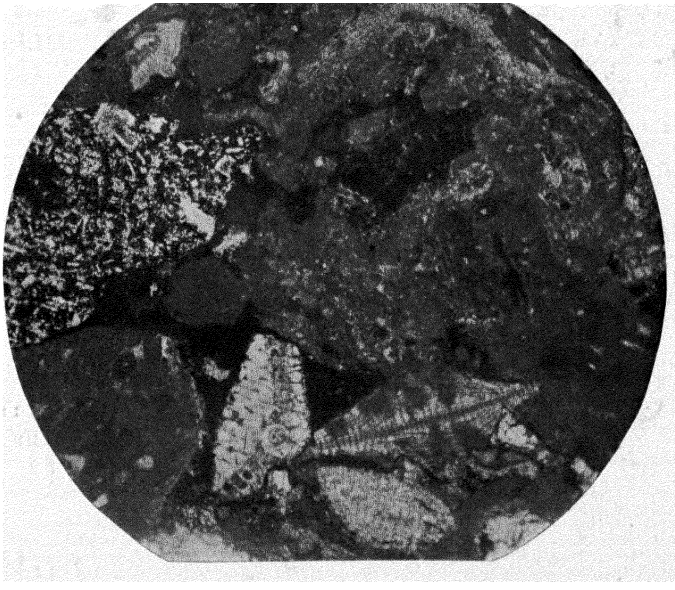


Fig. 2. Serpentine from Batan Island.

PLATE 6.



1



2

PLATE 7. FORAMINIFERAL LIMESTONE FROM SAMAR.

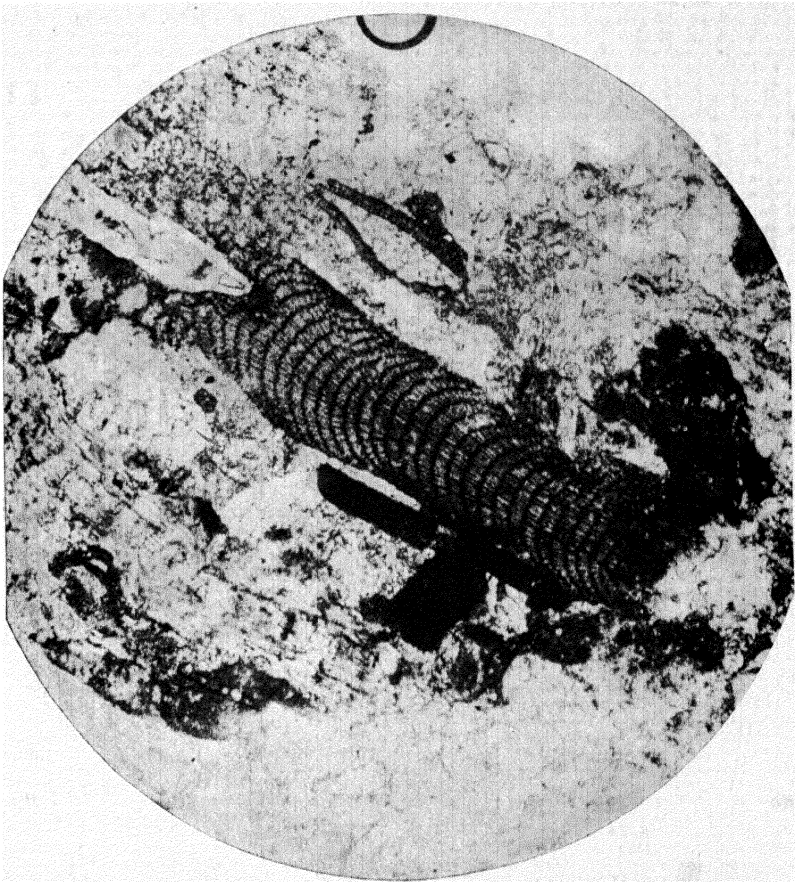


PLATE 8. LITHOTHAMNIUM RAMOSISSIMUM REUSS.

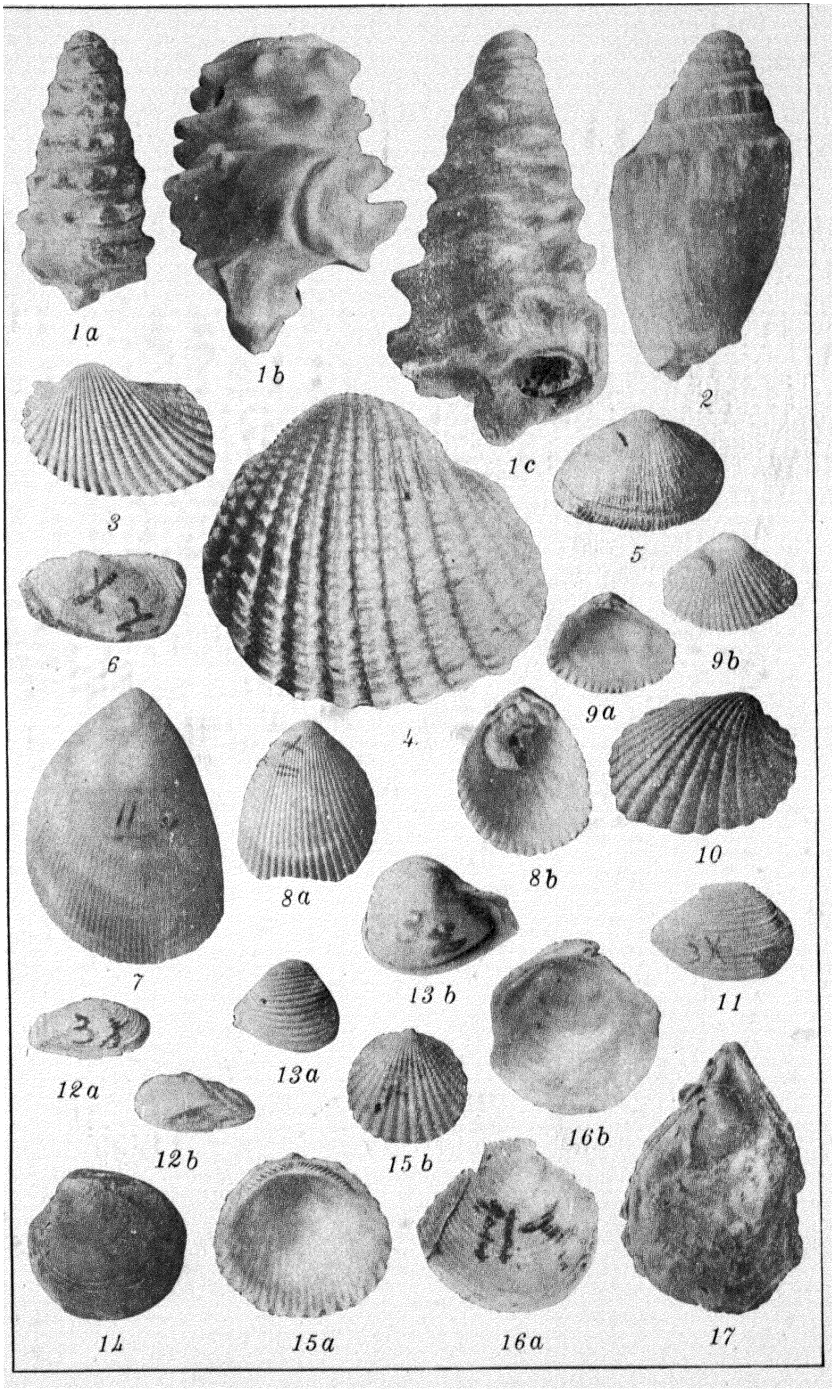


PLATE 9. VIGO GROUP, MIOCENE FOSSILS.

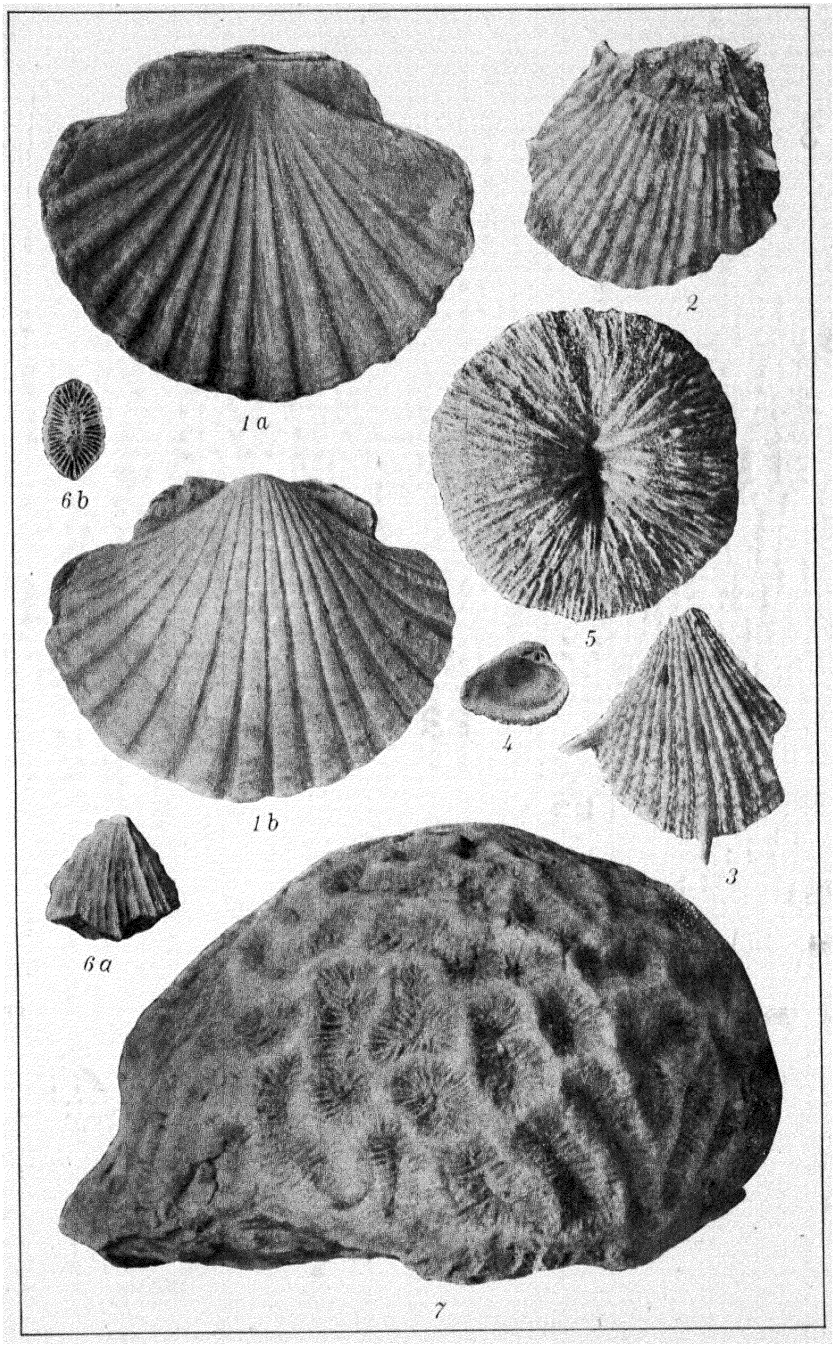


PLATE 10. MALUMBANG FORMATION, PLIOCENE FOSSILS.

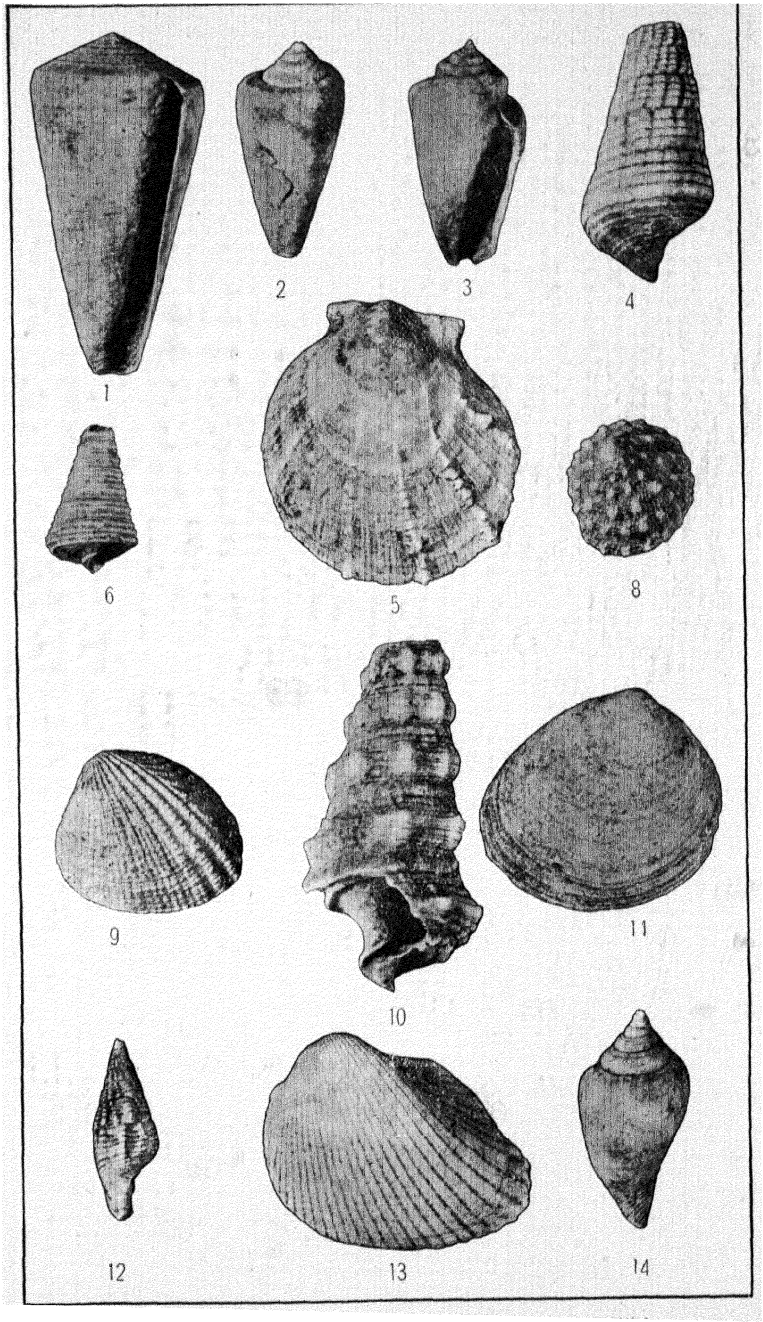


PLATE 11. PLEISTOCENE FOSSILS FROM BONDOC PENINSULA.

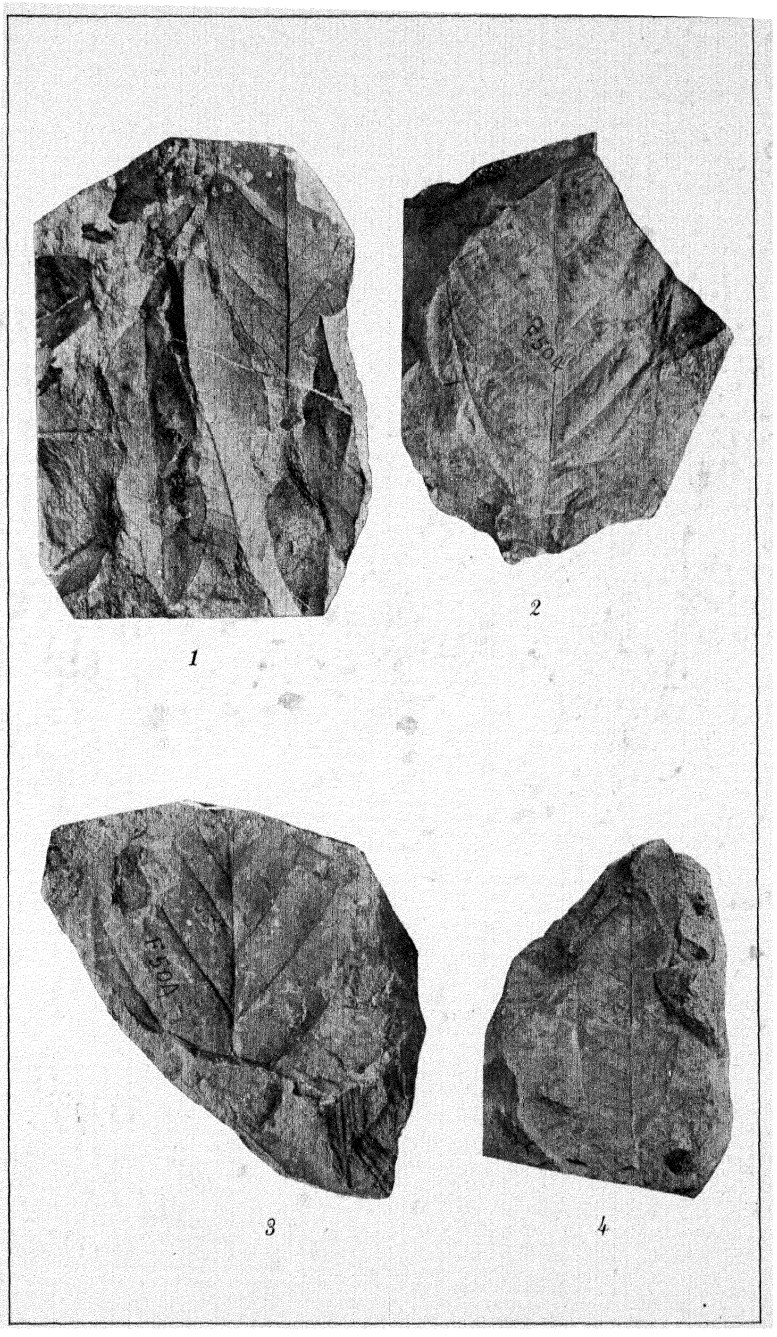


PLATE 12. MALUMBANG FORMATION, PLIOCENE FOSSILS.

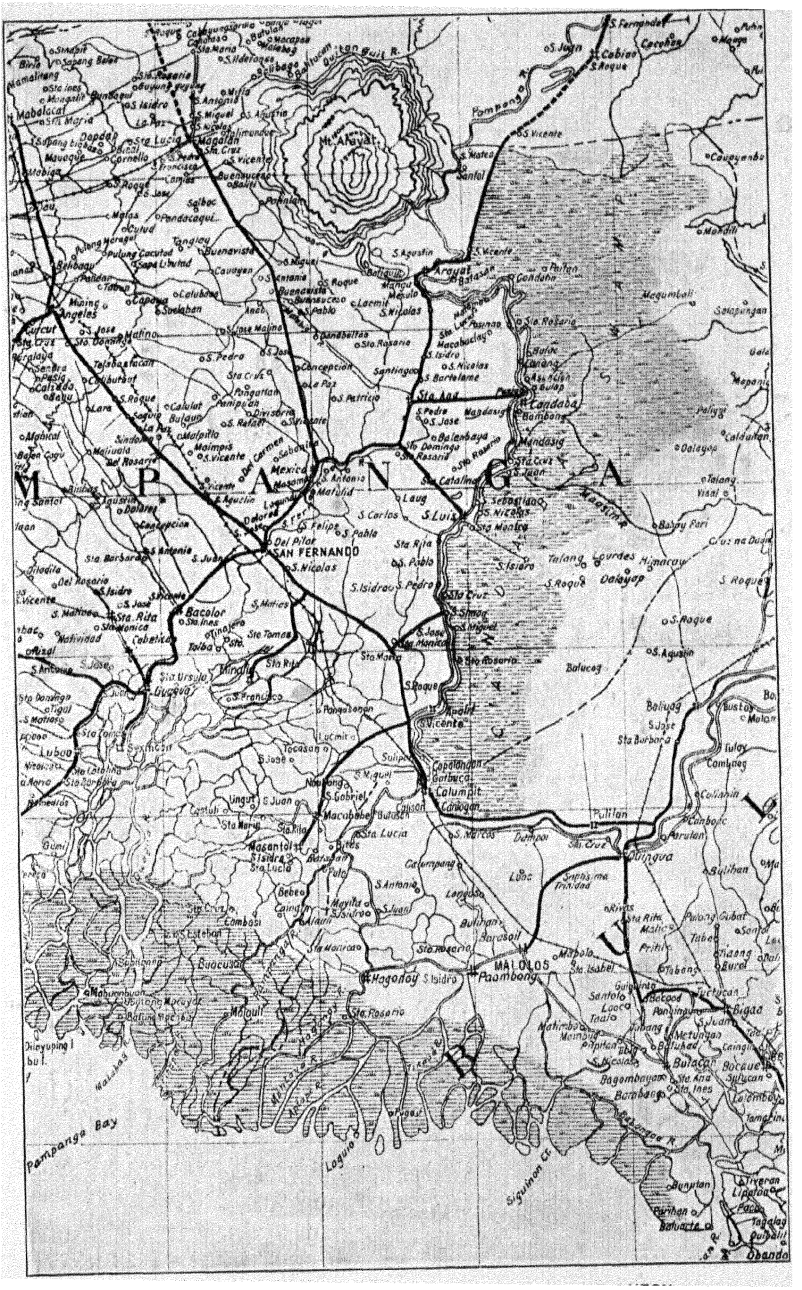


PLATE 13. A PORTION OF THE CENTRAL PLAIN OF LUZON.

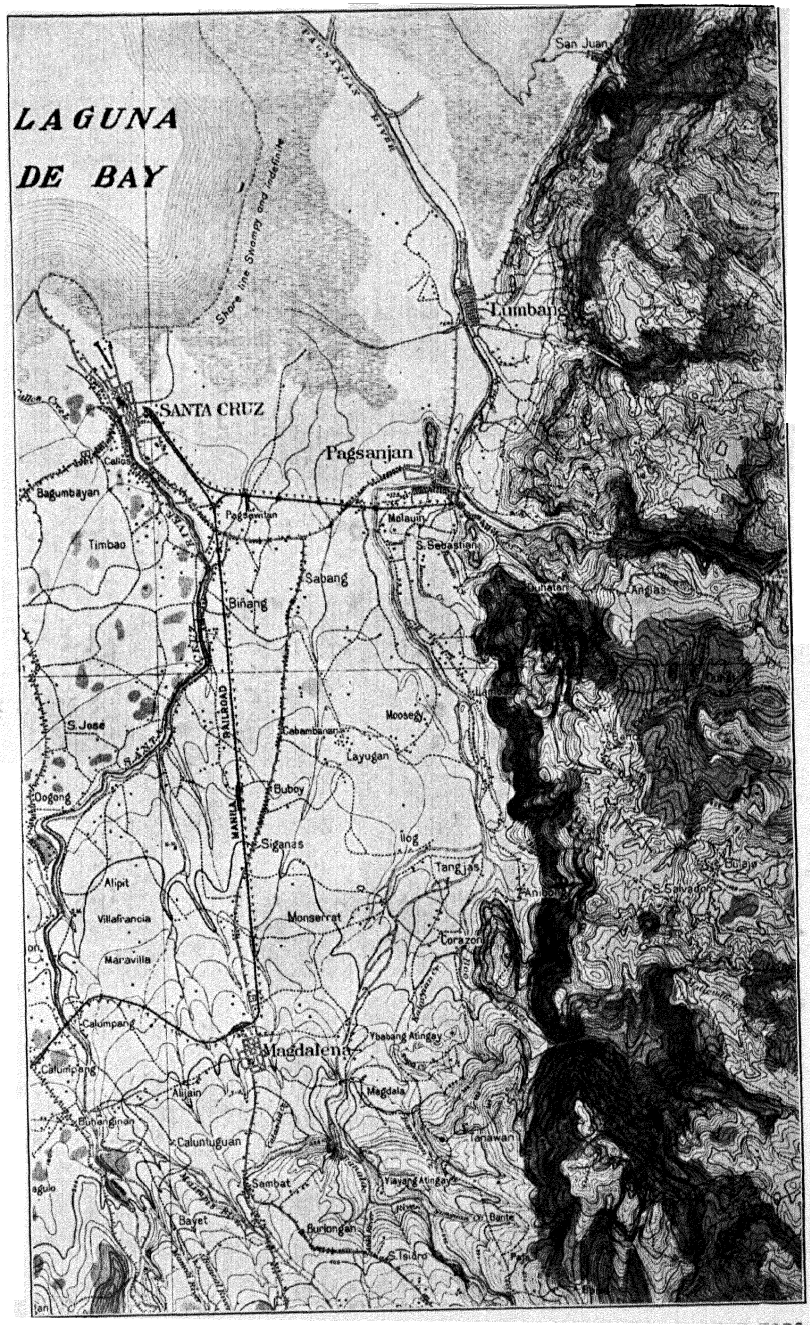


PLATE 14. THE EASTERN PORTION OF LAGUNA DE BAY AND THE ADJACENT TOPOGRAPHY.

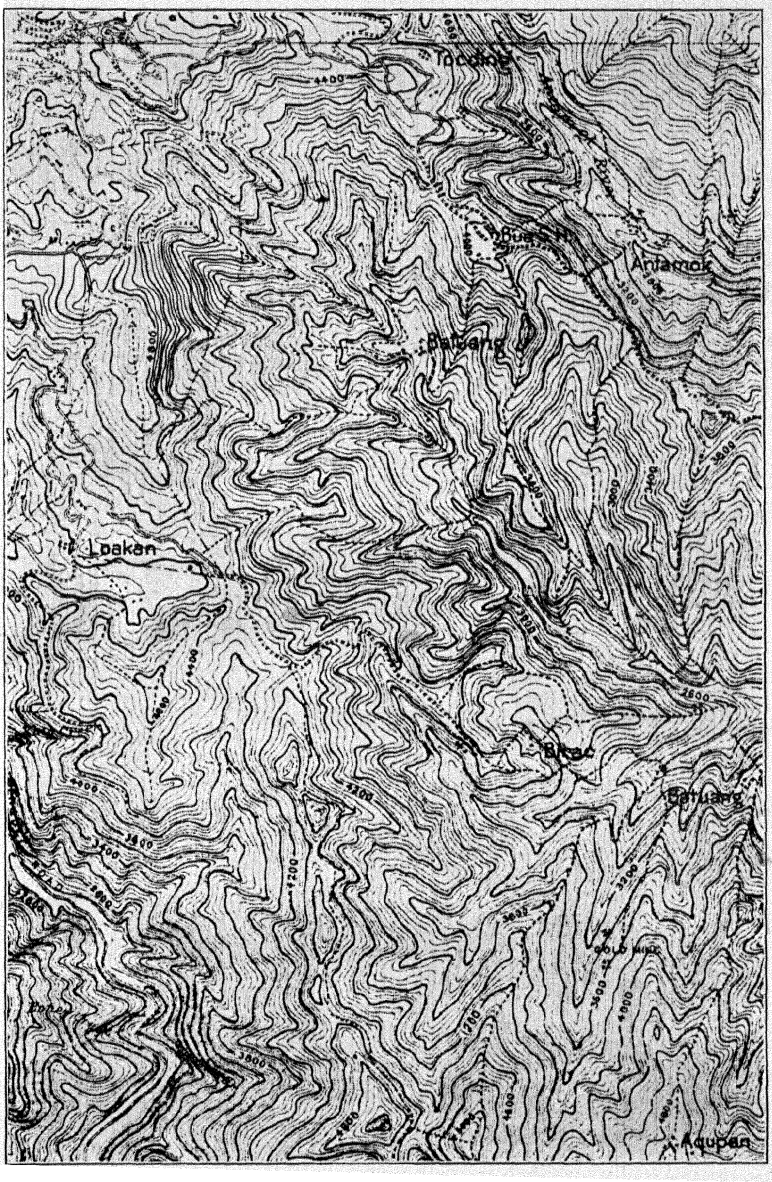


PLATE 15. THE BENGUET MINERAL REGION.

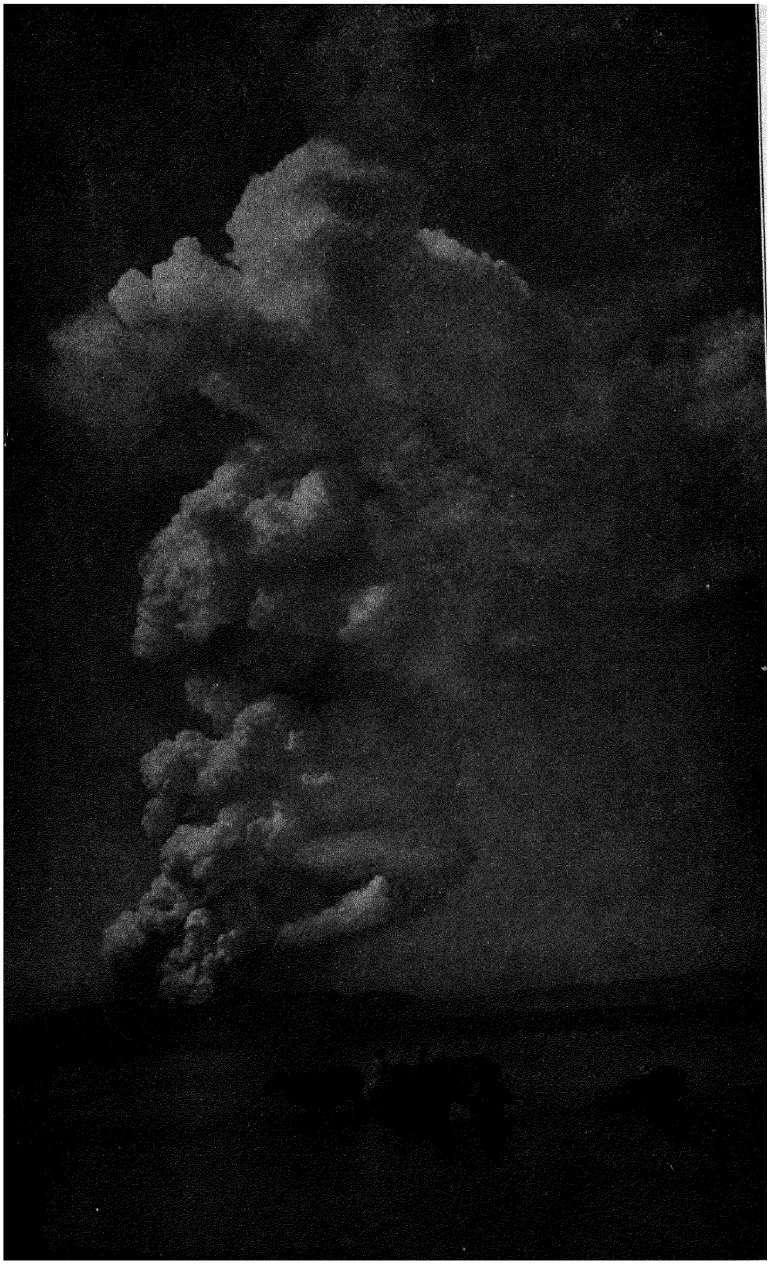


PLATE 16. ERUPTION CLOUD ABOVE TAAL VOLCANO AS IT APPEARED FROM BANADERO.



Fig. 1. Topography in the vicinity of Pidatan oil seep, Mindanao.

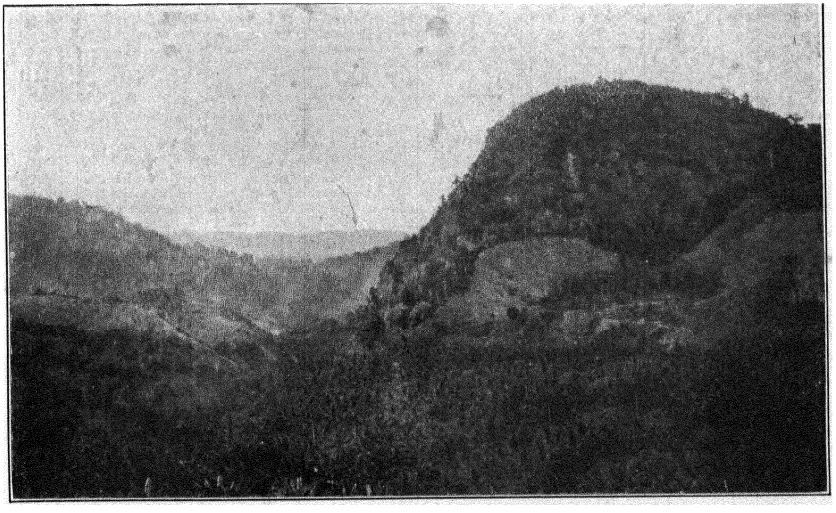


Fig. 2. Mount Kitubud (Pliocene limestone), and valley of the Malitabug.

PLATE 17.

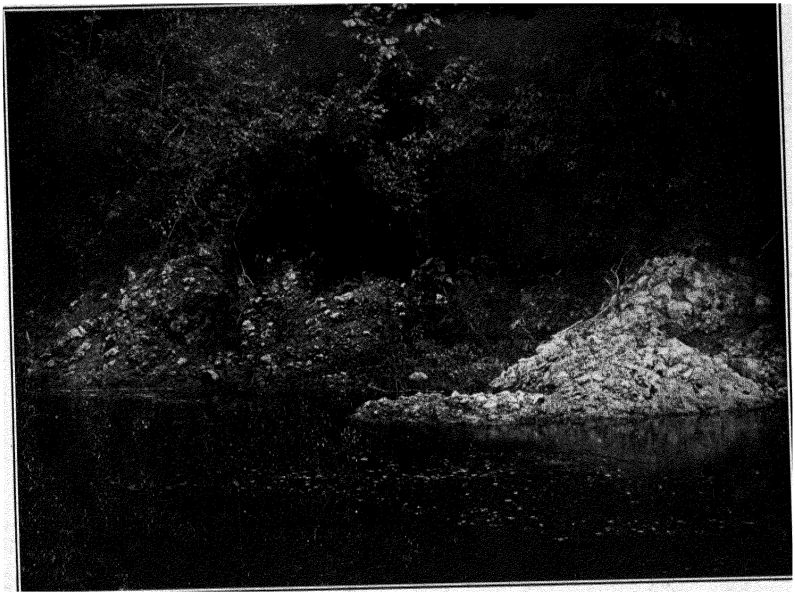


Fig. 1. Andesitic aggiomerata in Tumaga River.



Fig. 2. Tuff near Los Baños.

PLATE 18.



Fig. 1. Abra Water Gap.

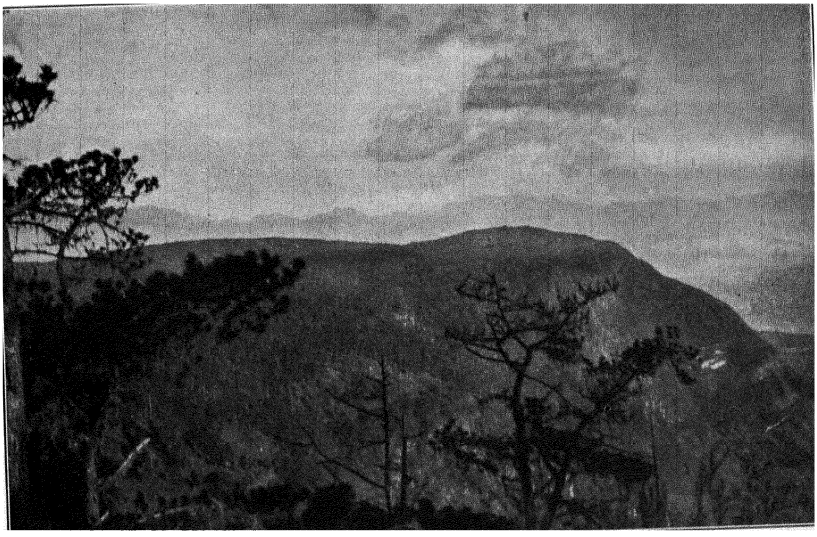


Fig. 2. Mount Data Plateau.

PLATE 19.

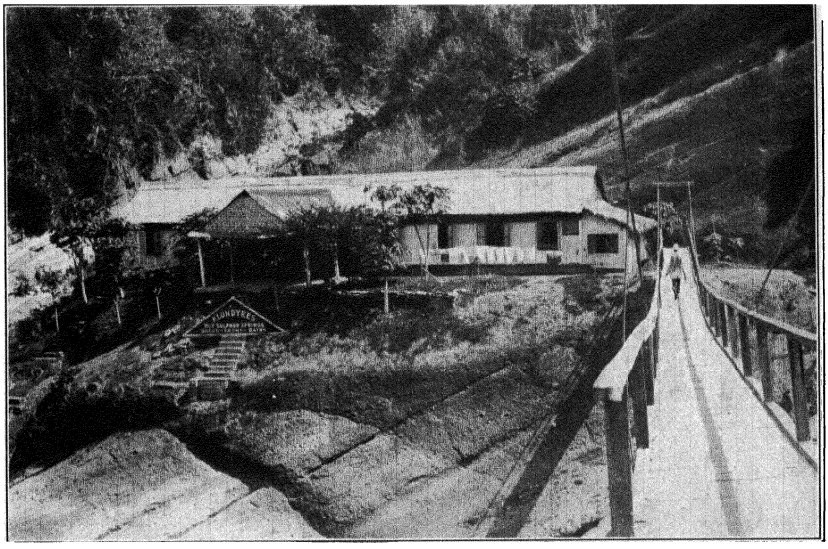


Fig. 1. Conglomerate beds at Klondyke's, Bued River Luzon.

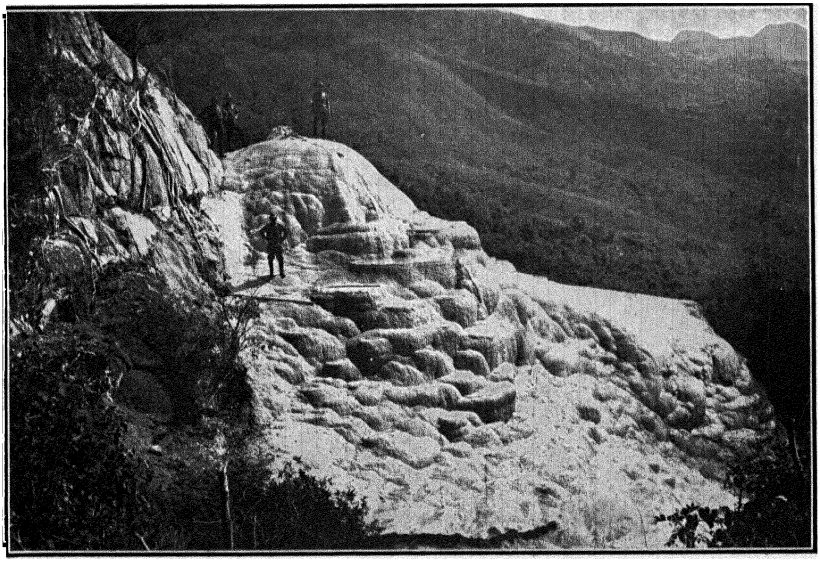


Fig. 2. Terraces at Salinas salt spring, Nueva Vizcaya, Luzon.

PLATE 20.

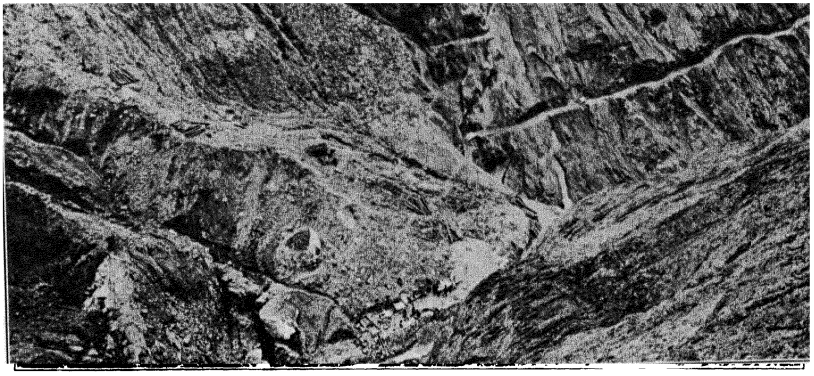


Fig. 1. Palidan slide, Suyoc, Mountain Province, Luzon.

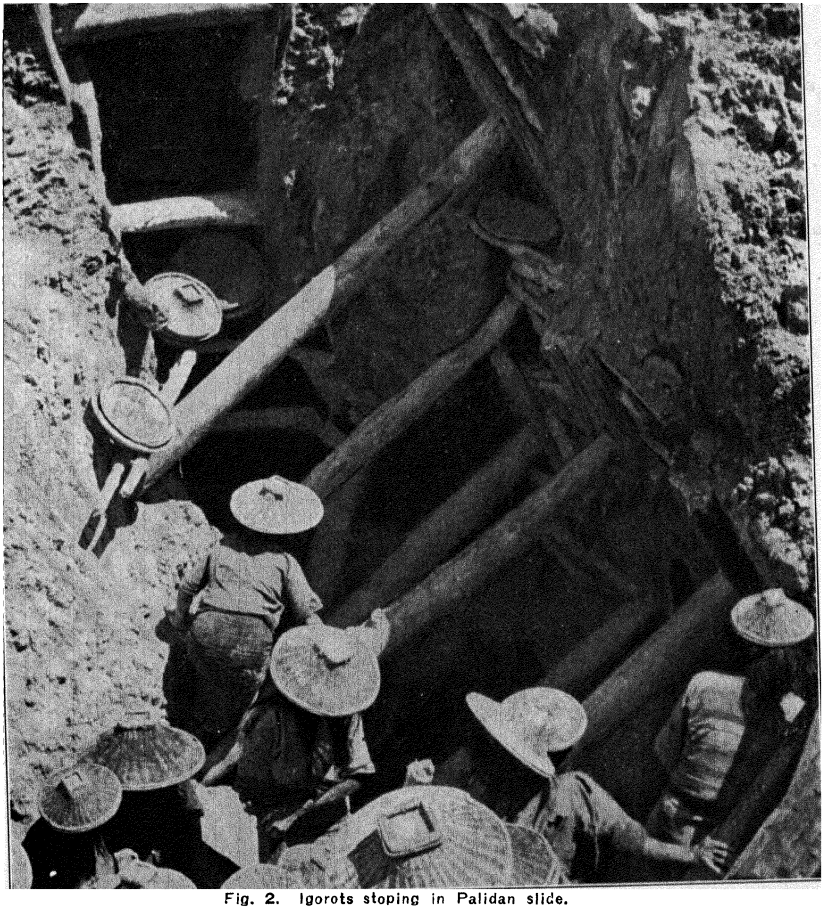


Fig. 2. Igorots stoping in Palidan slide.

PLATE 21.

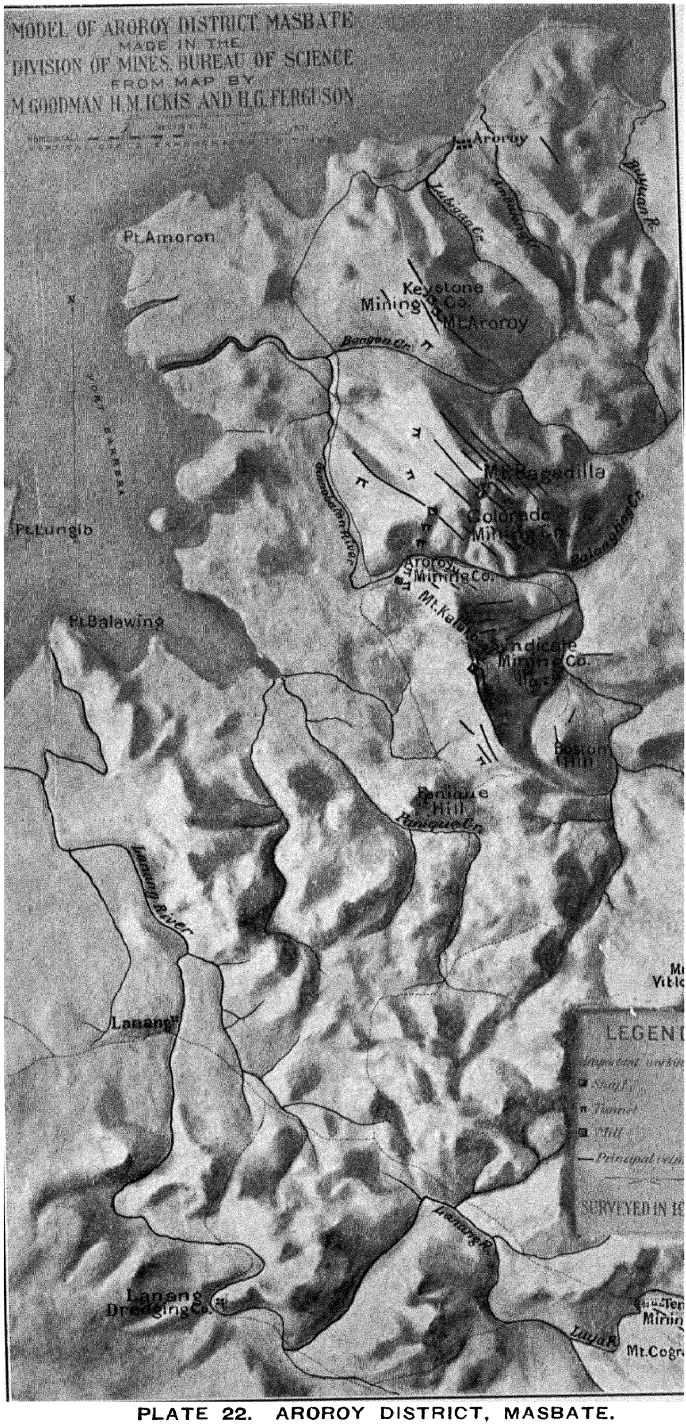


PLATE 22. AROROY DISTRICT, MASBATE.

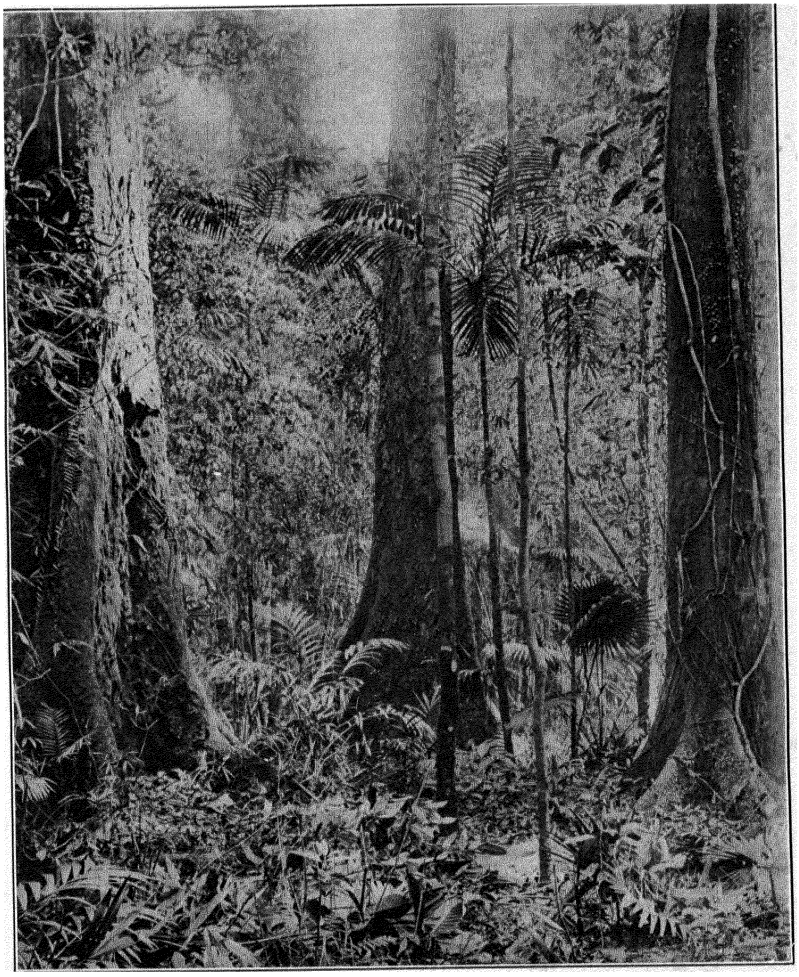


PLATE 23. INTERIOR OF A DIPTEROCARP FOREST ON THE LOWER SLOPES OF MOUNT SILAY, NEGROS. THE TREES ARE RED LAUAN AND ALMON, SPECIES OF SHOREA.

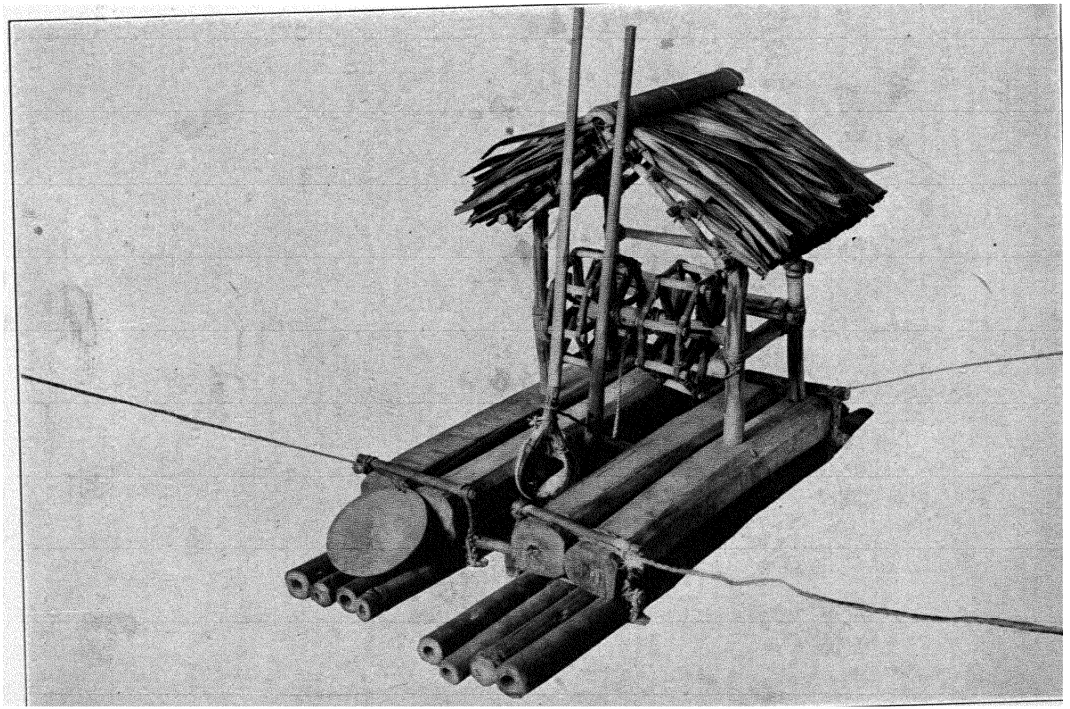


PLATE 24. MODEL OF A FILIPINO DREDGE IN USE IN AMBOS CAMARINES IN 1908.



PLATE 25. A VIEW IN CEBU, SHOWING ALLUVIAL CLAY FLOOD PLAIN OF PANDAN RIVER IN THE FOREGROUND; PLIOCENE LIMESTONE BEDS DIPPING TOWARD THE SEA IN THE DISTANCE.

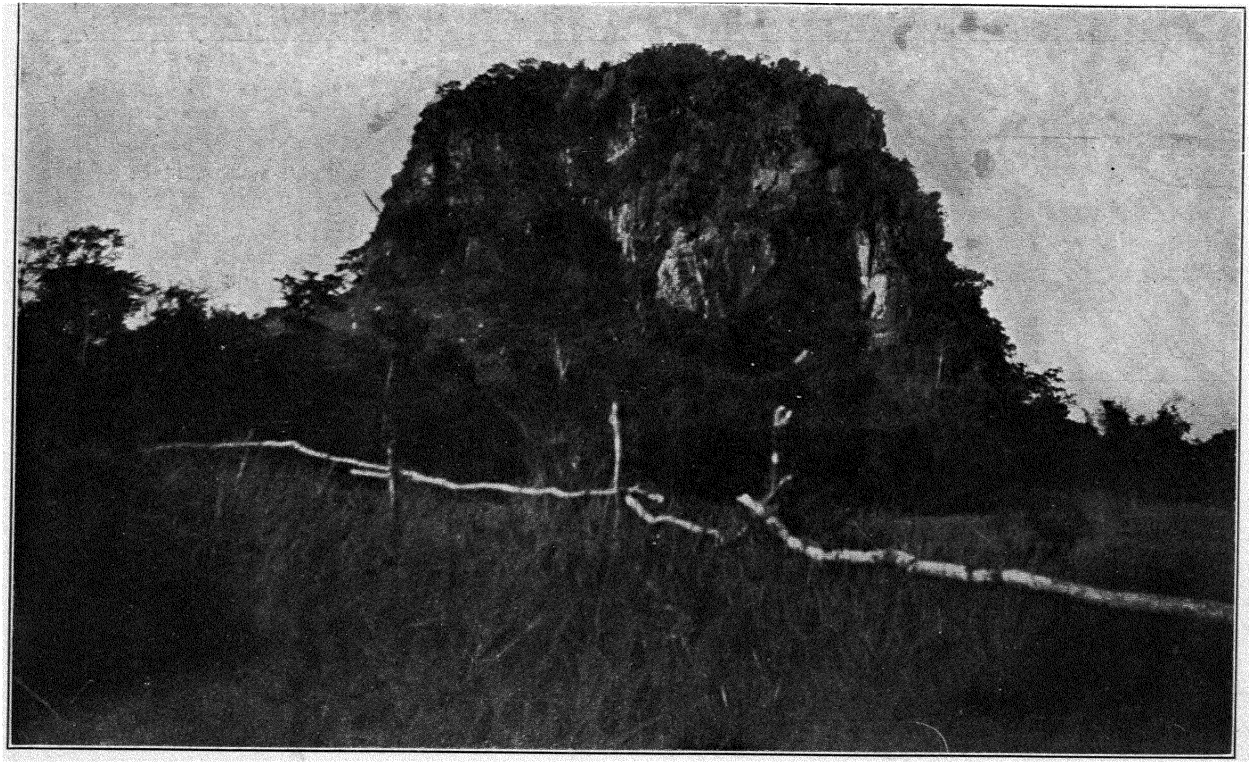


PLATE 26. LIMESTONE MONADNOCK, SITE OF THE BATWAAN CAVES, MASBATE.

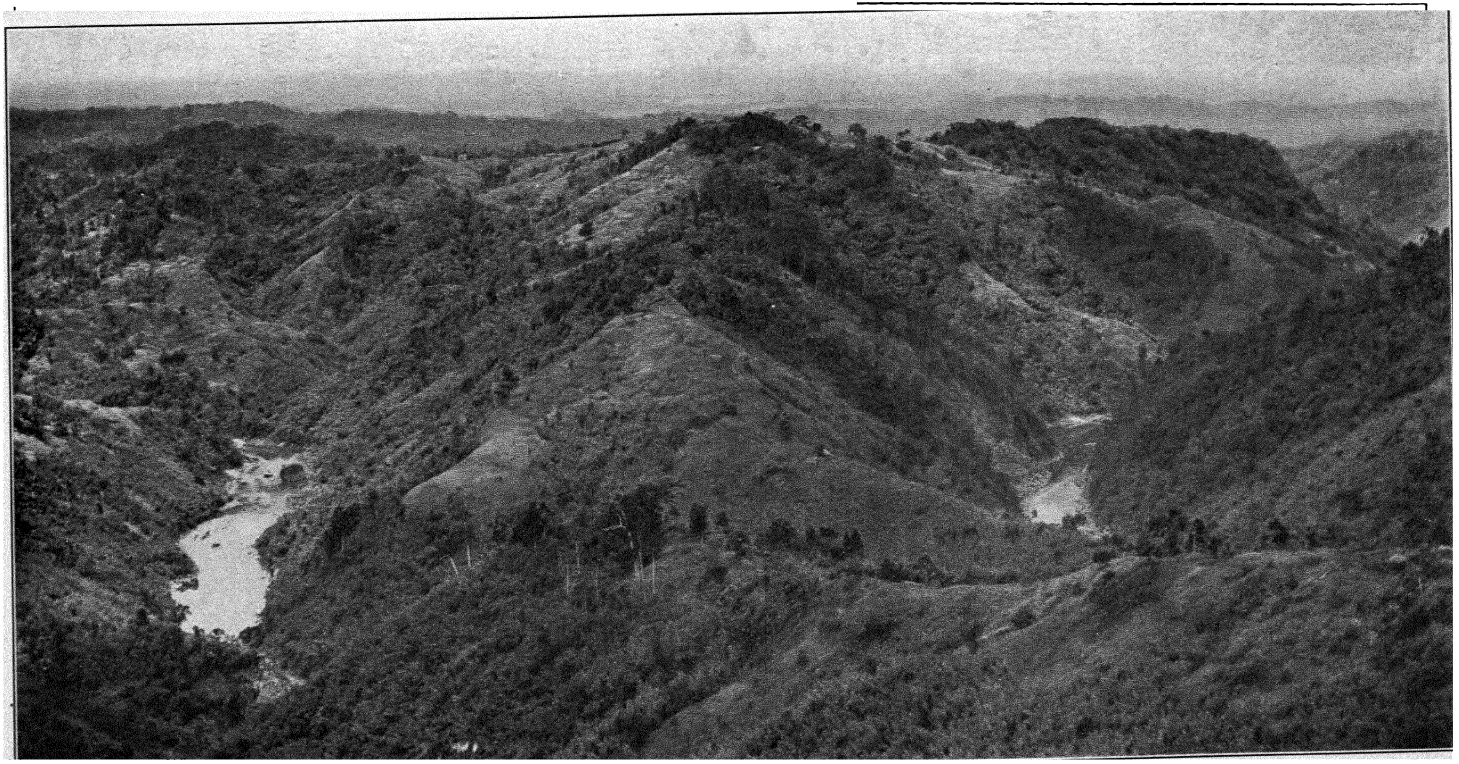


PLATE 28. ANGAT RIVER AT PAILA, BULACAN PROVINCE, LUZON.



PLATE 29. MAYON VOLCANO, ALBAY PROVINCE, LUZON; LEGASPI IN THE FOREGROUND.

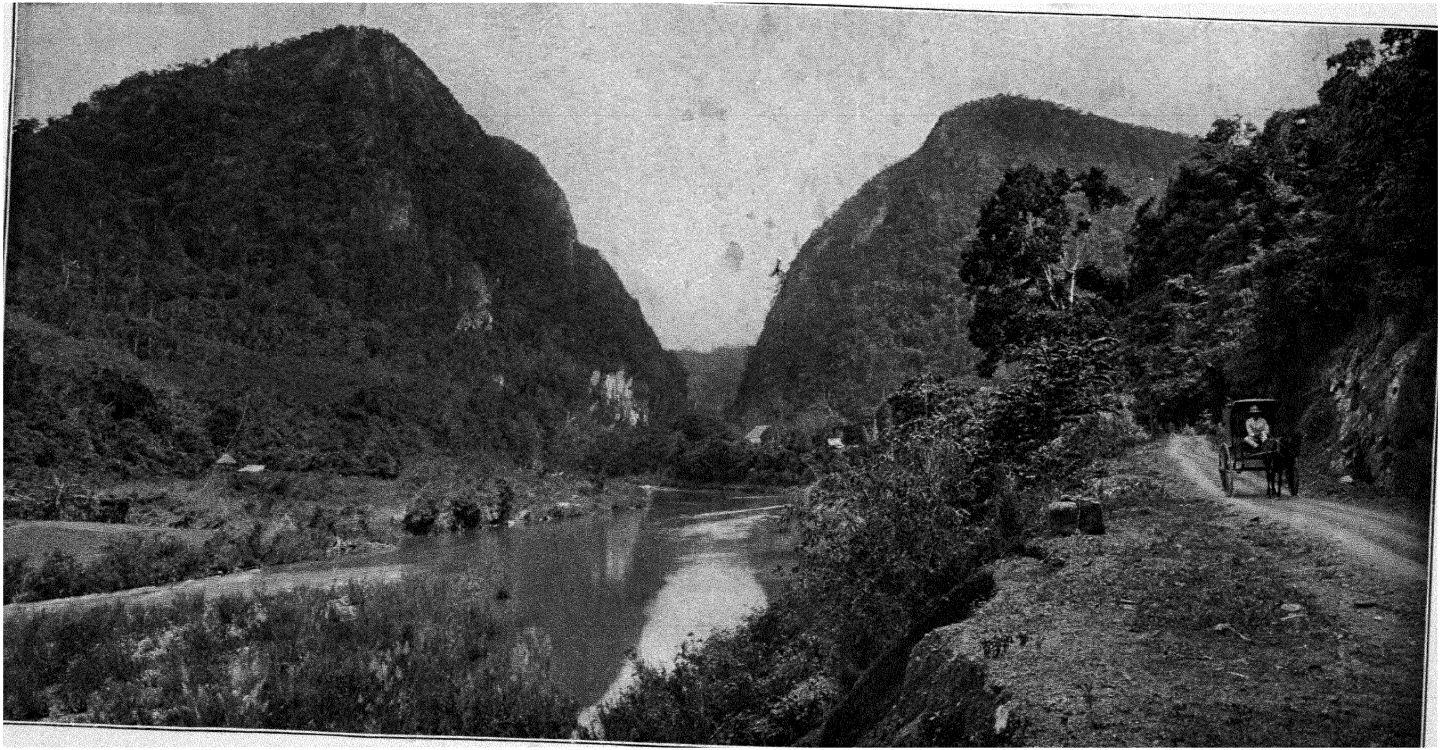


PLATE 30. MONTALBAN GORGE, RIZAL PROVINCE, LUZON, IN MIOCENE LIMESTONE CLIFFS.



PLATE 31. MOUNT APO, AS SEEN FROM DIGOS ON DAVAO GULF.



PLATE 32. CANLAON VOLCANO, NEGROS; INTERIOR OF THE CRATER.

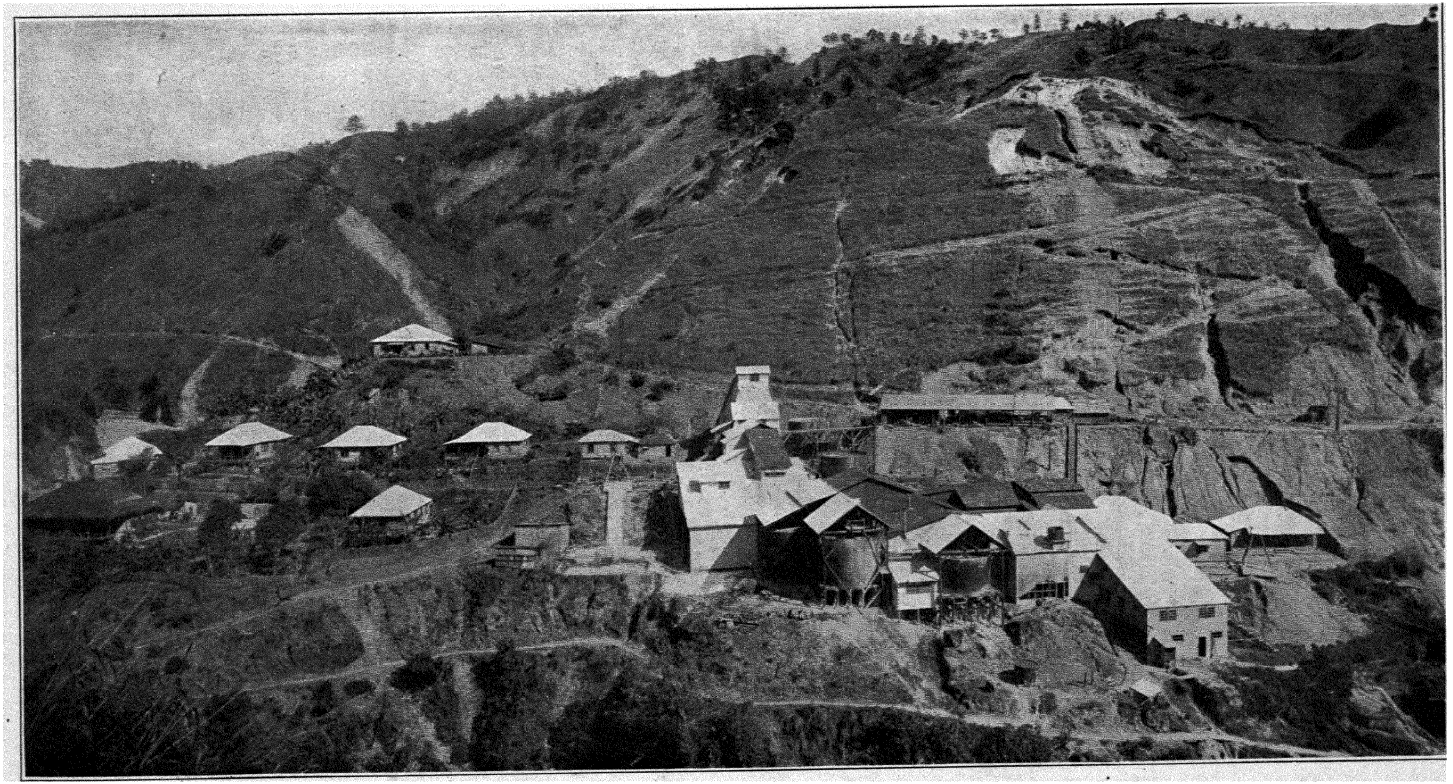


PLATE 33. BENGUET CONSOLIDATED MILL, ANTAMOK, MOUNTAIN PROVINCE, LUZON.



PLATE 34. MOUNT BANAHAO, LAGUNA PROVINCE, LUZON.

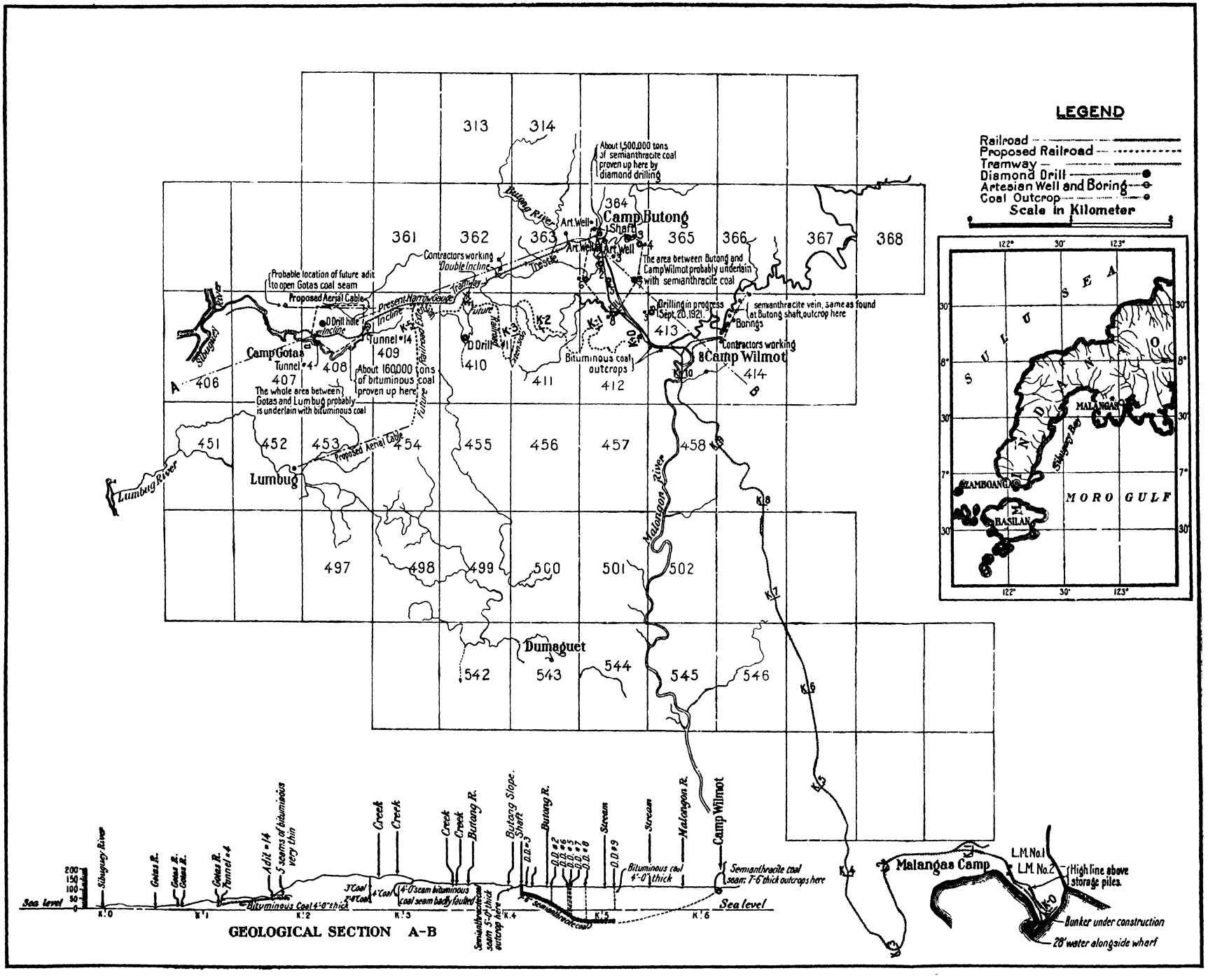


PLATE 36. THE SIBUGUEY COAL FIELD, MINDANAO.

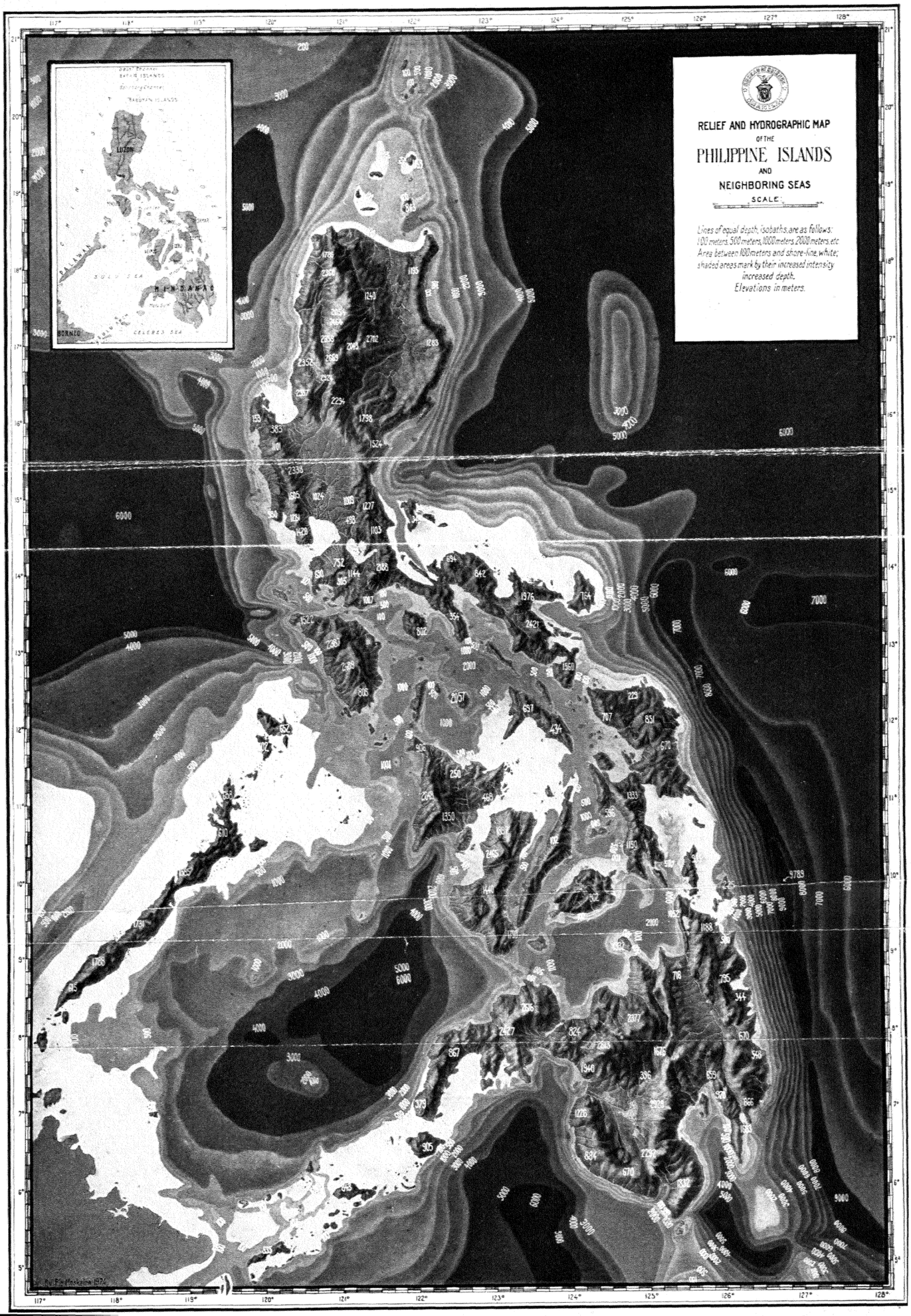
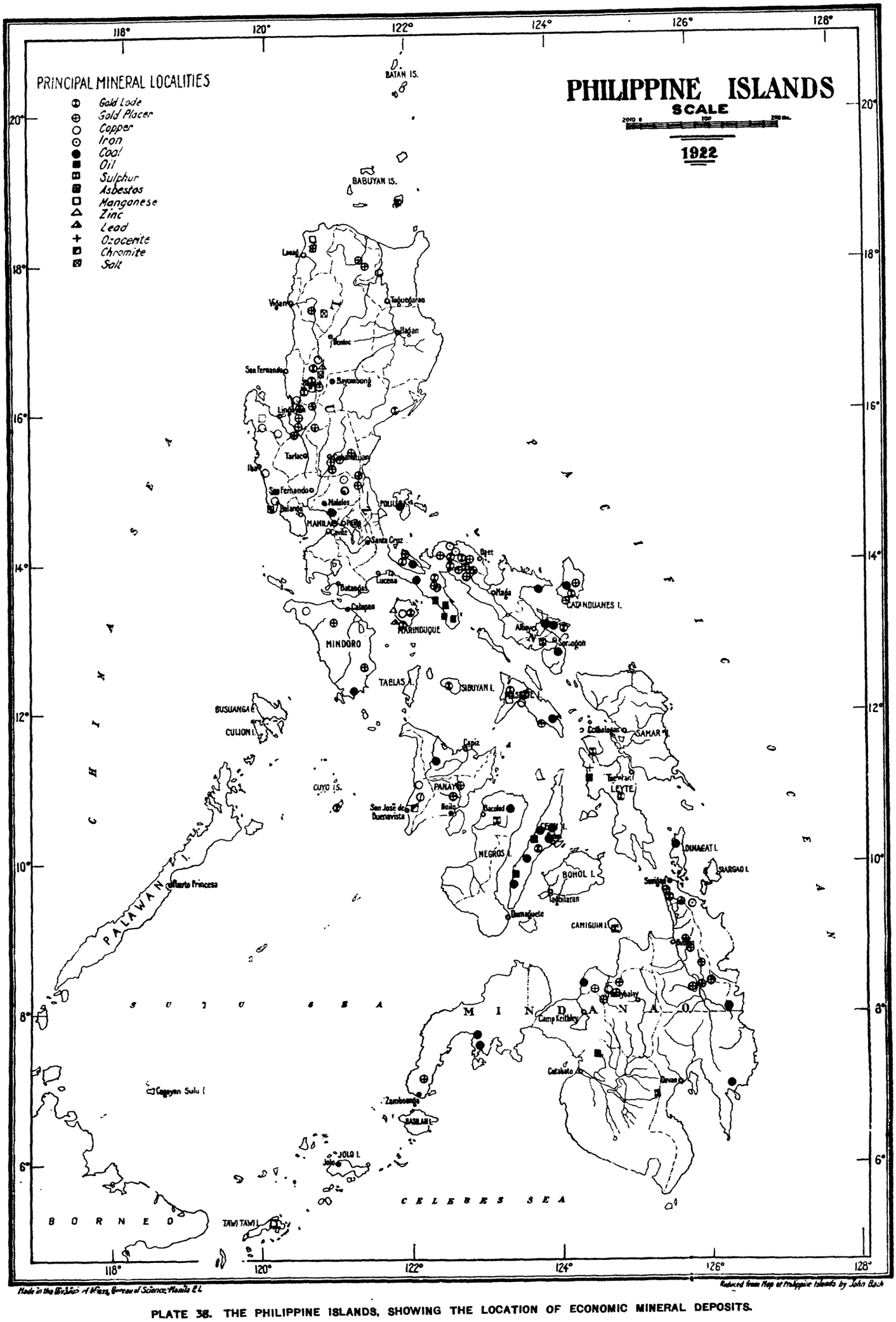


PLATE 37. THE PHILIPPINE ISLANDS. SHOWING THE RELIEF.



Made in the Division of Mines, Bureau of Science, Manila P.I.

Reduced from Map of Philippine Islands by John Bach

PLATE 38. THE PHILIPPINE ISLANDS, SHOWING THE LOCATION OF ECONOMIC MINERAL DEPOSITS.

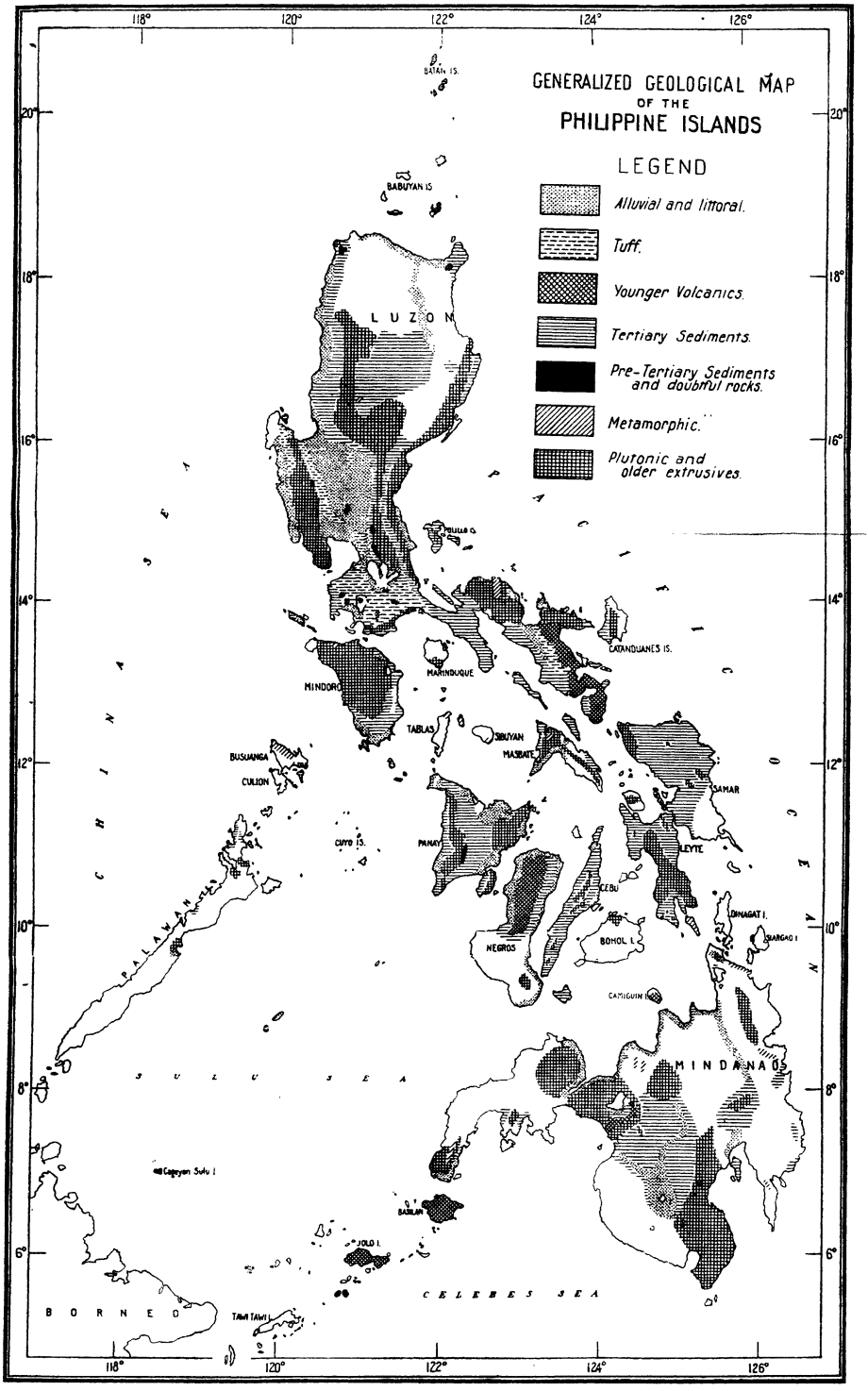


PLATE 39. THE PHILIPPINE ISLANDS, SHOWING THE GEOLOGIC FORMATIONS.

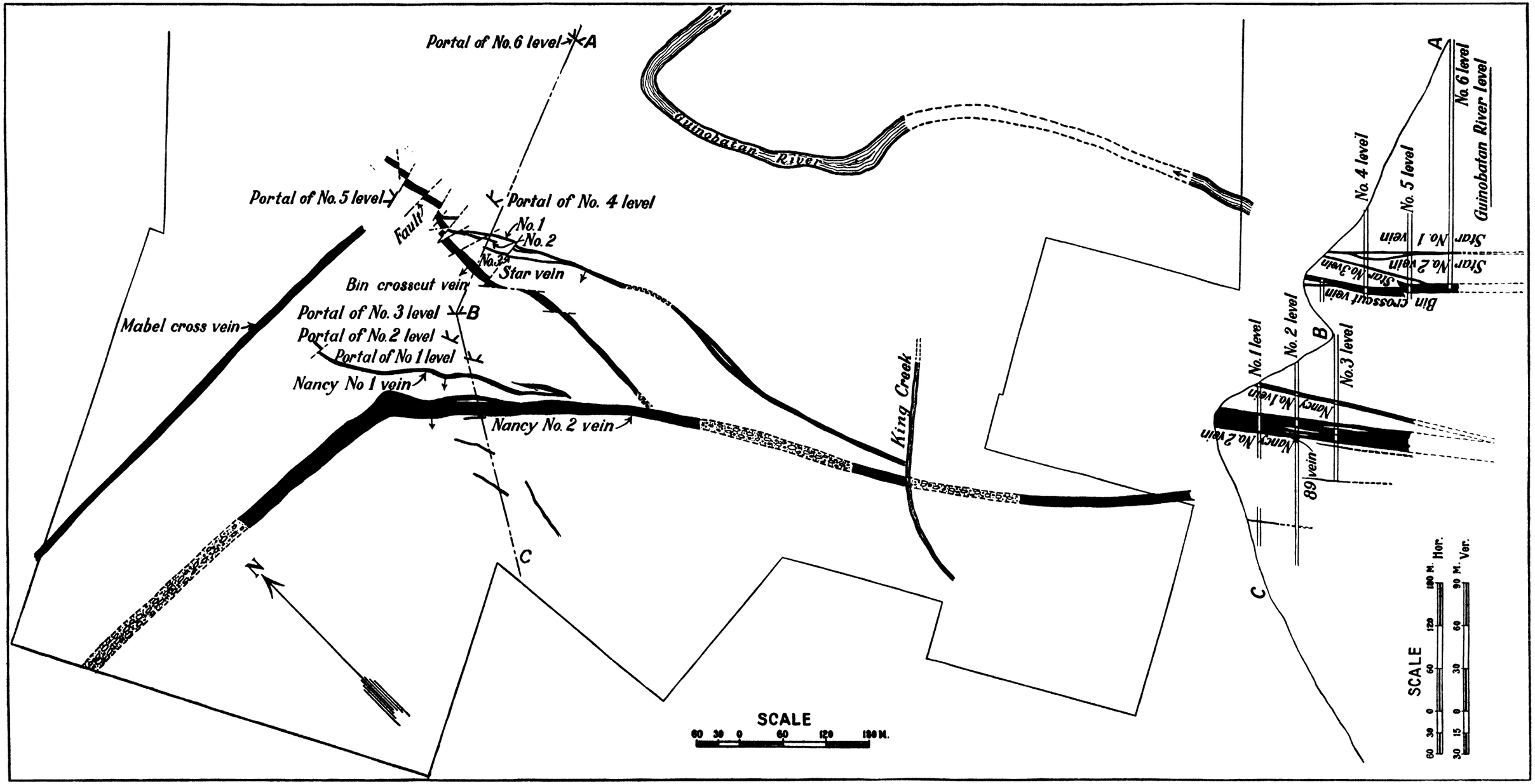


PLATE 35. VEIN SYSTEM ON THE SYNDICATE PROPERTY, ARoroy, MASBATE